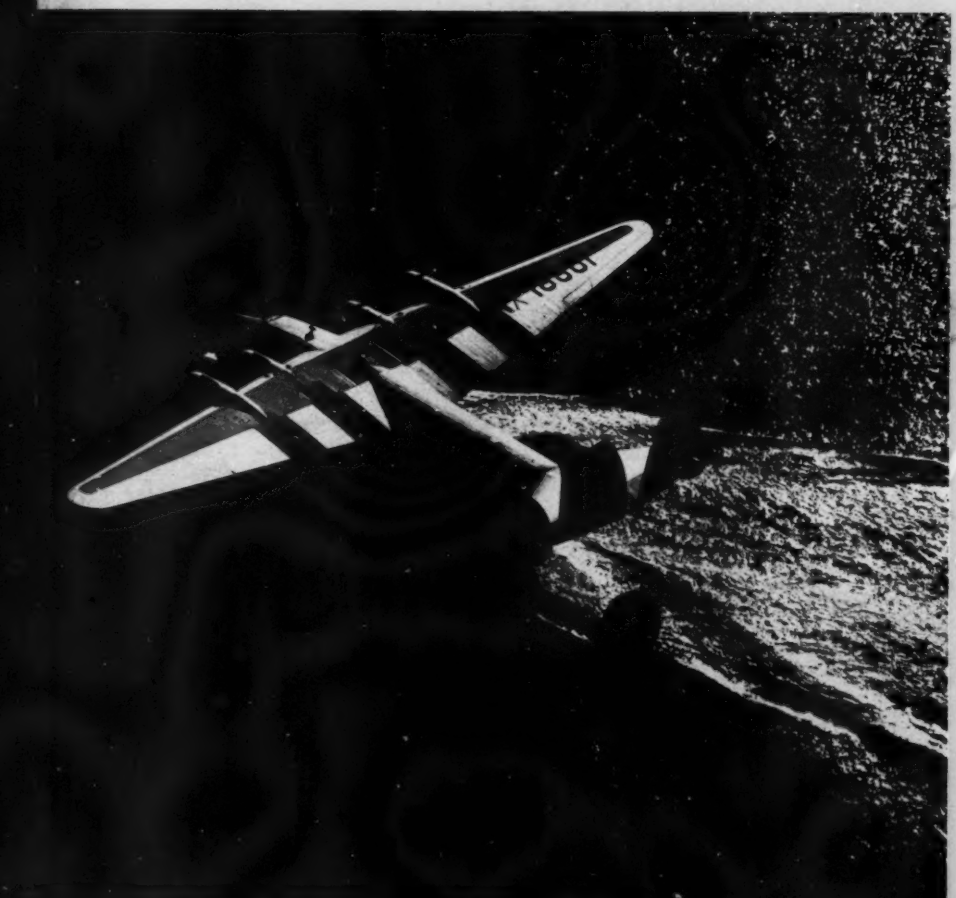
The TREND IN ENGINEERING

at the University of Washington

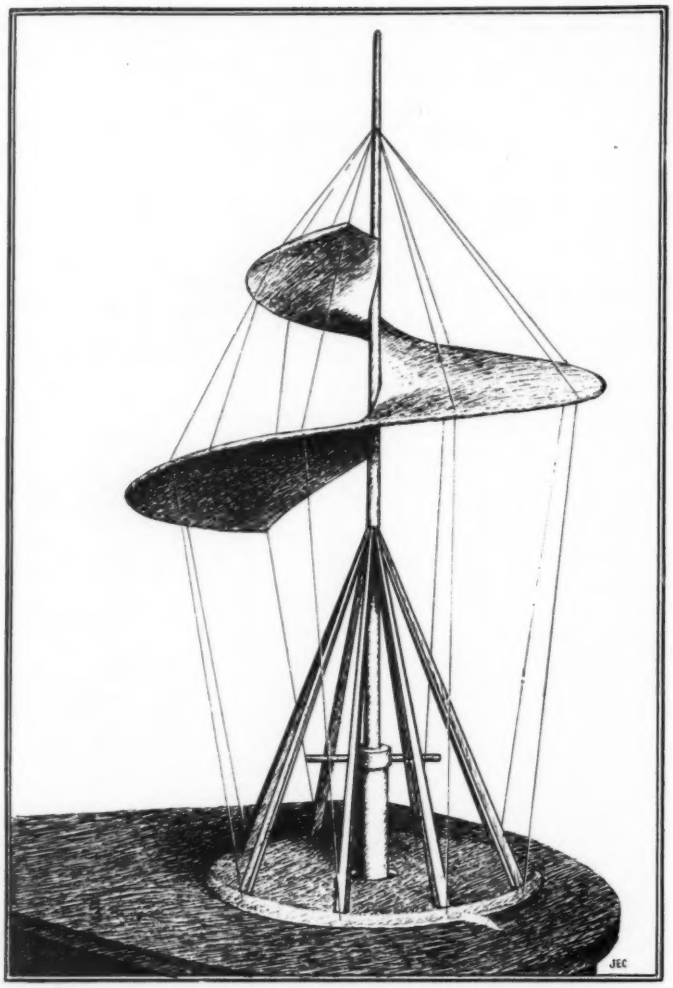


In this issue:

- University of Washington Aeronautical Laboratories
- Gasification of Washington Coals by Water-Gas Process
- Fourth Northwest Conference on Road Building
- Mineral Industry Institute
- Microwave Radio Links for Island Communication
- Electrode-Electrolyte Temperature Differentials
- Stresses in Timber Truss Joint
- Slip of Structural Steel Double-Lap Joints with High-Strength Bolts
- Flame Propagation Velocities

April, 1951

VOL. 3, No. 2



Drawing based upon reproduction of model in *An Exhibition of the Scientific Achievements of Leonardo da Vinci,* New York Museum of Science and Industry, Vigo Press, 1940.

Aerodynamic Design in the 15th Century

"If the accomplishment be not for me, 'tis for some other; the spirit cannot lie; and man, who shall know all and shall have wings, shall indeed be as a god."

—Leonardo da Vinci, 1452-1519.

IN HIS DESIGN for an aerial screw, Leonardo da Vinci heralded the helicopter and visualized the forerunner of the modern propeller. Motive power planned for this model, which apparently was never built, was to consist of a spring-driven mechanism operating in the manner of modern clockwork. Specifications outlined in his notes were as follows:

"Let the outer extremity of the screw be of steel wire as thick as a cord, and from the circumference to the centre let it be eight braccia [about 15 ft.]. I find that if this instrument made with a screw be well made—that is to say, made of linen of which the pores are stopped up with starch—and be turned swiftly, the said screw will make its spiral in the air and it will rise high.

"Take the example of a wide and thin ruler whirled very rapidly in the air, you will see that your arm will be guided by the line of the edge of the said flat surface.

"The framework of the above-mentioned linen should be of long stout cane. You may make a small model of pasteboard, of which the axis is formed of fine steel wire, bent by force, and as it is released it will turn the screw."

—All quotations are from *The Notebook of Leonardo da Vinci*, arranged and rendered into English by Edward MacCurdy, Reynal and Hitchcock, New York, 1941-42.

THE ENGINEERING EXPERIMENT STATION of the University of Washington was established in December, 1917, to coordinate investigations in progress and to facilitate the development of engineering and industrial research in the University. Its purpose is to aid in the industrial development of the state and nation by scientific research and by furnishing information for the solution of engineering problems.

The scope of the work is three-fold:

(1) to investigate and publish information concerning engineering problems of a more or less general nature that would be helpful in municipal, rural, and industrial affairs;
(2) to undertake extended research and to publish reports on engineering and scientific problems;
(3) to provide opportunities for graduate engineers to conduct research under conditions that will most effectively prepare them for professional service.

For administrative purposes the work of the Station is organized into nine divisions:

1. Aeronautical Engineering
2. Chemical Engineering, Industrial Chemistry
3. Civil Engineering
4. Electrical Engineering
5. Forest Products
6. Geology
7. Mechanical Engineering
8. Mining, Metallurgy, Ceramics
9. Physics Standards and Tests

The control of the Station is vested in a Station Board consisting of the President of the University, the Dean of the College of Engineering as chairman, the Director of the Station, and members of the faculty, representative of the administrative divisions. The Board determines the character of the investigations to be undertaken and supervises the work.

The Station offers a substantial number of research fellowships to highly qualified graduate students who work under the direct supervision of the faculty of the various divisions. The results of the investigations are published in the form of bulletins, technical notes, and reports. Reprints of articles by members of the engineering faculty and graduate students published in recognized technical journals are also issued by the Station. Requests for copies of the publications and inquiries for information on engineering and industrial problems should be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

April, 1951

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at the University of Washington

Vol. 3 No. 2

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Engineers in the News
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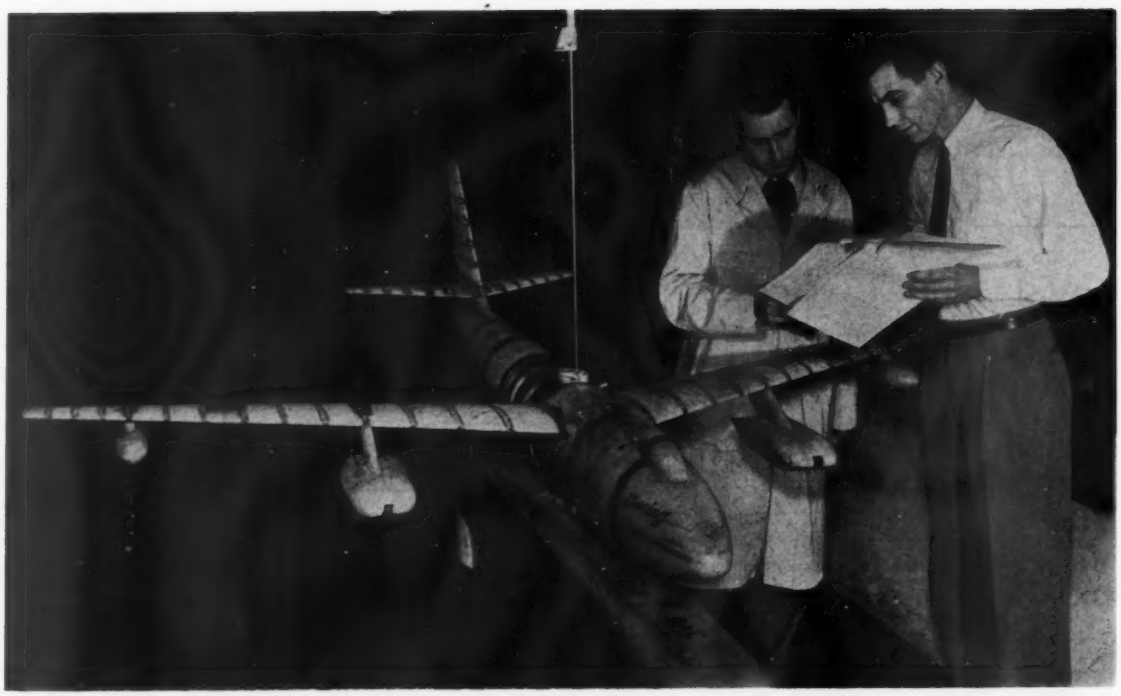
COVER

The Boeing 314 Clipper, the most famous transoceanic flying boat, appeared in 1938. Capable of carrying up to 89 people, it had a wing span of 152 ft; length, 106 ft; height, 27 ft 7 in; gross weight, 84,000 lb (slightly more than Columbus' *Niña*); top speed, 199 mph; maximum range, 5,000 miles; 4 Wright Cyclone GR-2600 engines, 1,700-hp each.

Inset: The B-1 of 1919, an all-wooden flying boat, carried the first contract international airmail—between Seattle and Victoria, B. C. During 10 years' service on the 76-mile run, with Eddie Hubbard as pilot, it logged more than 350,000 miles, wore out 6 engines. Originally designed for a Hall-Scott engine, it was later changed to incorporate the 400-hp Liberty-12 mounted as a pusher between the wings. It accommodated two passengers and the pilot in open cockpits.

Both photos courtesy of Boeing Airplane Company



ABOVE (*left to right*): **W. ALLEN AND R. H. SMITH IN UNIVERSITY WIND TUNNEL WITH BOEING MODEL**
BELOW: **UNIVERSITY WIND-TUNNEL CREW** (*left to right*): **Students G. PETERS, W. ALLEN, RAY PROUTY; Research Associate R. H. SMITH; Student L. WILEY; Supervisor R. G. JOPPA**

Photographs courtesy of Boeing Airplane Company

UWAL

The University of Washington Aeronautical Laboratories

V. M. GANZER

Associate Professor of Aeronautical Engineering

V. M. Ganzer

The recent signing of a contract between the Boeing Airplane Company and the University of Washington for modernization of the F. K. Kirsten 8-ft by 12-ft wind tunnel has served to re-emphasize the importance of the aeronautical laboratories in the life of the University and of the state of Washington and the nation as a whole.

The Boeing Airplane Company has contracted to give the University of Washington Aeronautical Laboratories $20,000 and to lend up to $20,000 in addition, upon condition that the balance system of the wind tunnel be revised to permit removal of any part of the balance or support system from the wind-tunnel test section. Also, an attempt is to be made to insulate parts of the wind-tunnel building with regard to noise, in order to improve working conditions. In return, the Aeronautical Laboratories have guaranteed Boeing certain priorities on testing time for the next two years, during which the Boeing wind tunnel will be remodeled.

The University of Washington Aeronautical Laboratories started with the construction of the Boeing Aerodynamical Chamber in 1918. This wind tunnel, built with the cooperation of the "Boeing Aeroplane Shop," established only two years before, was certainly one of the pioneer wind tunnels in the western part of the United States, and is still used by students in Aeronautical Engineering.

The original tunnel (50 mph) was used in the development of some of the first Boeing airplanes, such as the PW-9 and others. Active on the campus at the time of its use were Professors E. O. Eastwood and F. K. Kirsten. Professor F. B. Farquharson, present director of the Engineering Experiment Station, and Robert J. Minshall, later chief engineer at Boeing, were students in engineering at the time, and in 1921 rehabilitated the tunnel and carried on some work for Boeing.

The next major addition to the Aeronautical Laboratories was the 8-ft by 12-ft 250-mph wind tunnel which bears the name of the man who, more than any other, was responsible for its acquisition—F. K. Kirsten.

The need for this facility was linked directly in the mind of Professor Kirsten with the studies he was making on the application of cycloidal propulsion to aircraft. The tunnel was designed and built in the middle nineteen thirties, and was ready for testing in 1938. Much of the design work on the tunnel was done by Professor Kirsten and Professor Fred S. Eastman, the present executive officer of the Department of Aeronautical Engineering. The electrical balance system, unique at the time, was developed by Professor Eastman, and has since been copied extensively in other wind-tunnel balance systems throughout the country. The National Physical Laboratory at Teddington, England, has also adopted the Eastman balance system for one of its wind tunnels.

F. S. EASTMAN

At the time the Kirsten wind tunnel was under way, Boeing again came to the aid of the University with a loan of $26,000 to help in its construction, to be paid back to Boeing in testing time in the new laboratory.

Thus, by 1938, the University was provided with one of the most modern aerodynamic test facilities in the United States. It proved a timely acquisition, for shortly after its opening, the Second World War broke out, and a race began to design and build

F. K. Kirsten

new aircraft superior to those used by the enemy. Test facilities available to aircraft companies were comparatively scarce in the years just prior to our entrance into the war, as well as during the early war years, and the 8-by-12 tunnel was booked solidly with tests for commercial concerns.

The use of the tunnel by the aircraft companies has continued throughout the years, even though many companies now have wind tunnels of their own. During this time many famous airplanes were tested as models in the tunnel. Among them were many of the commercial and military airplanes built by the Lockheed Aircraft Corporation, many Boeing airplanes, such as the 314 Clipper, the Stratoliner, the B-17, the B-29, the Stratocruiser, the 6-jet B-47, and others. The McDonnell Banshee, Phantom, Voodoo, and Goblin (illustrated) were tested, as were the Vultee Vengeance, and various Douglas and Curtiss airplanes. In fact, the contribution of the University Aeronautical Laboratories to the development of aircraft in the past decade has been considerable, even if regarded only as providing a precision aerodynamic tool.

Another result of the commercial testing is that the UWAL have been self-supporting, and have not only provided part-time employment for many students, but have been able to provide equipment for the use of the Aeronautical Engineering Department as well.

Other activities than commercial testing have been carried on in the wind tunnel. Many tests have been made of the cycloidal propulsion system for aircraft, for instance, and a renewed interest in this subject at this time promises more development work for the future.

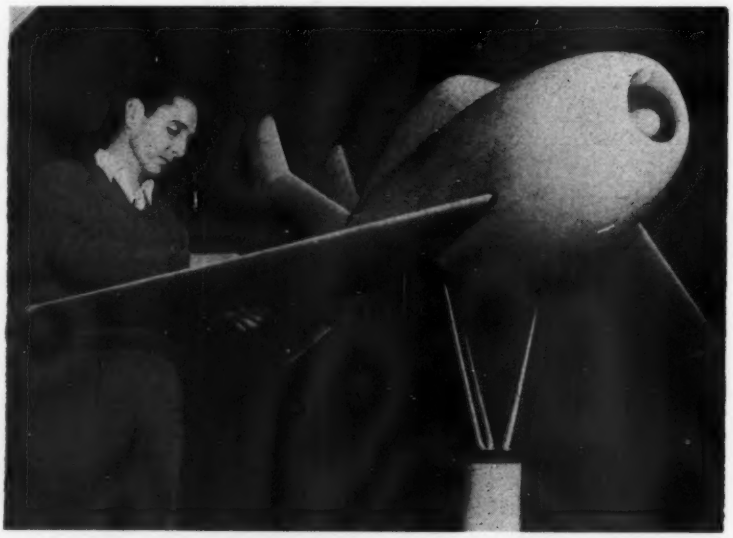
A testimony to the soundness of design of the present wind tunnel and balance is the fact that several wind tunnels have been built following these design features. The Lockheed wind tunnel is quite similar to that of the University of Washington, and the wind tunnel of the Boeing Airplane Company uses many of the features incorporated at the University of Washington. The electric balances have been particularly successful, and the principles of their design have been used very successfully in other applications.

E. O. Eastwood

The history of the UWAL would not be complete without mention of the newest facilities—the supersonic tunnels. Two small supersonic tunnels have been built under the supervision of Mr. G. E. Ledbetter, a former student in aeronautical engineering, with funds earned by the Kirsten wind tunnel. Funds were also contributed by the Engineering Experiment Station for research fellowships and instrumentation.

The present organization of UWAL is much the same as it has been since its inception. The executive officer of the Department of Aeronautical Engineering has the final authority, but delegates much of it to the Supervisor of UWAL, Robert Joppa. Another permanent staff member, R. H. Smith, works half time for UWAL, but students do most of the work, including operation of the tunnel, reduction and computation of test data, repair and maintenance of equipment, and design and construction of new apparatus. Twenty students are now employed part time.

The projected revision of the balance system of the F. K. Kirsten tunnel reminds us that the UWAL are ever preparing to meet the complex needs of aeronautical education, research, and development.



A. S. CROSSFIELD WITH WIND-TUNNEL MODEL OF McDONNELL "GOBLIN"

Mr. Crossfield is now Chief Test Pilot at the NACA High-Speed Flight Test Laboratory, Muroc, California

GASIFICATION OF WASHINGTON COAL BY A CONTINUOUS WATER-GAS PROCESS*

R. W. EVANS
Research Fellow, Engineering Experiment Station

R. W. MOULTON
Professor of Chemical Engineering

R. W. Evans

Introduction

Southwestern Washington coal is largely low-grade bituminous, subbituminous, and lignite. It is unsuitable for conventional fuel use because of its high ash and oxygen content with resultant low heating value. It is not good coking coal. A typical lignite sample from Lewis county near Toledo, Washington, has the following analysis:

Proximate Analysis		*Ultimate Analysis*	
Moisture	32.6%	Hydrogen	6.8%
Volatile matter	26.6%	Carbon	36.2%
Fixed carbon	24.7%	Nitrogen	0.5%
Ash	16.2%	Oxygen	39.8%
Heating value	6,200 Btu/lb	Sulfur	0.5%
		Ash	16.2%

This type of coal should be suitable for gasification by some of the newer methods[1, 2, 3, 4, 5] by which continuous gasification can be achieved, employing oxygen and steam in a suspended pulverized coal bed.†

Water-Gas Reaction

The classical concepts of reactions taking place in the fuel bed of conventional type water-gas generators are no longer useful in improving water-gas processes and are not applicable to the development of fluidized processes. Recent theory of carbon gasification considers a gas film covering the surface of the carbon particle. Under certain conditions diffusion of gases through the gas film controls the reaction rate, while under other conditions the reaction rate is determined by the rate of chemical reaction. Experiments on the oxidation of carbon at temperatures below 1350° F show that the reaction rate is primarily a function of temperature, while at higher temperatures the reaction rate is primarily a function of gas velocity. This would indicate that the chemical resistance controls the reaction rate at lower temperatures and that diffusion controls at higher temperature.[6, 7] The actual mechanism of the reactions on the surface of the carbon has been suggested[7] to be the primary formation of complexes with secondary decomposition of the complexes to carbon monoxide, carbon dioxide, and hydrogen. The reactivity of the carbon surface has been shown to have a large effect on the reaction rate and may have an effect on equilibrium. After consideration of the above principles, a reactor was designed for the gasification of the low-grade coal.

R. W. Moulton

Design and Construction of Experimental Gasification Unit

Inasmuch as hot surfaces catalyze both heterogeneous and homogeneous reactions, the objective of this design was to facilitate a maximum residence time for the coal particles in the chamber. This design consists of a vertical tube (Fig. 1) supported in the center of a concentric vertical cylindrical chamber. A nozzle projects from the roof of the chamber into the top of the inner cylinder or tube so that there is an open annular space between the inner cylinder and the nozzle. An exhaust port is located at the bottom of the chamber. A pipe projects up through this port into the lower end of the inner cylinder in the same manner as the nozzle, i.e., leaving an annular opening between pipe and inner cylinder. Pulverized coal in a gaseous suspension passes through the nozzle, down the inner part of the tube, then up around the tube in the annular space between the chamber and the tube, and then down through the tube again. In this manner a maximum circulation of the suspension is obtained. Other necessary gas, in addition to the gaseous suspension of coal, enters the chamber through the pipe which

* Condensed by N. R. Mukherjee, Associate in Chemical Engineering, from the thesis submitted by R. W. Evans for the degree of M.S. in Chemical Engineering, 1948. The Tono Coal used in this research was contributed by the Strain Mining Company.

† See Report No. 6 of the Engineering Experiment Station, 1950, "Chemical Utilization of the Subbituminous Coals of Washington" by L. A. Conradi, for a description of coal gasification processes.

projects into the lower end of the inner cylinder. Some of the suspension, instead of circulating, continues down through the annular space between the lower pipe and the walls of the exhaust port. This suspension then enters a cyclone-type fines separator in order to remove ash and unreacted coal. The product from the cyclone passes through a wash tower, and is then metered.

The unique part of the design consists of a vertical cylinder supported centrally within a larger cylindrical chamber with axes coinciding so that continuous circulation of the pulverized coal suspension, down through the inner cylinder and up through the annular space, is achieved. Product gas and suspension is continuously removed from the chamber through the annular space of the exhaust port. The reaction should initiate in the inner cylinder so that the highest temperature in the chamber is within the inner cylinder. The inner cylinder wall plus the gases in the annular space between the chamber wall and the cylinder should reduce radiation losses from the high-temperature zone. In addition, the flow characteristics of the suspension within the cylinder are determined by the relative velocities of the two opposite blasts into opposite ends of the inner cylinder: the gaseous coal suspension blasting from the nozzle at the top and the other gas from the open end of the pipe at the bottom of the inner cylinder.

No references could be found concerning this arrangement so that it was not known if the turbulent suspension would behave in the chamber as hypothesized. A model of the generator was constructed in order to study the actual flow characteristics. Both the small inner cylinder and the larger cylindrical chamber were made from plexiglas tubing and the remainder of the model was constructed with sheet metal and standard pipe fittings. Experiments were conducted with various mesh sizes of coal under different air-velocity conditions, and the following results were found for this particular model:

1. Circulation of the suspension took place exactly as hypothesized, but in addition there was an added clockwise (topview) rotational movement around the annular space. This was fortuitous because the path of the coal particles was increased by this spiral movement, thereby increasing the residence time.
2. Coal of size 48 mesh and finer circulated in suspension with 0.06 cu ft of air per second through the nozzle with no opposing blast. Coal of 35-48 mesh fluidized only with 0.5 cu ft of air per second through the nozzle with no opposing blast. Therefore, coal of 48 mesh and finer was found to be the best for this process.
3. The suspension circulation was effectively stopped by an equal amount of air from the upward opposing blast, but as long as the volumetric rate of flow from the nozzle exceeded that of the upward opposing blast the suspension of coal (48-mesh and finer) retained proper circulation. Circulation was stopped and no coal suspension issued from the nozzle as the upward opposing blast was increased to a slightly greater volumetric rate than the downward blast.
4. The maximum coal rate was approximately 9 lb per hour.

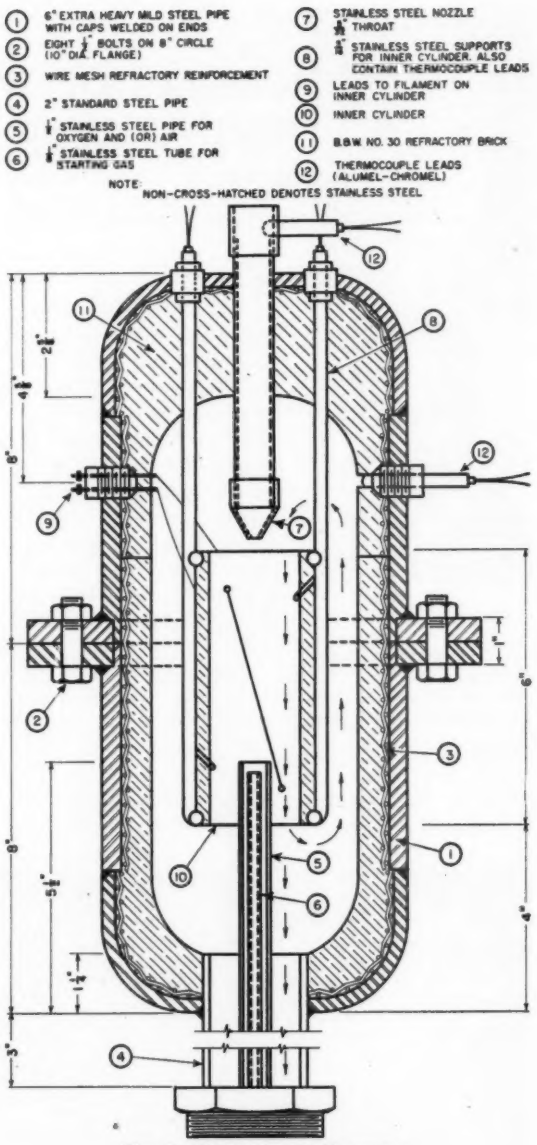

1 6" EXTRA HEAVY MILD STEEL PIPE WITH CAPS WELDED ON ENDS
2 EIGHT ¾" BOLTS ON 8" CIRCLE (10" DIA. FLANGE)
3 WIRE MESH REFRACTORY REINFORCEMENT
4 2" STANDARD STEEL PIPE
5 ¼" STAINLESS STEEL PIPE FOR OXYGEN AND (OR) AIR
6 ¼" STAINLESS STEEL TUBE FOR STARTING GAS
7 STAINLESS STEEL NOZZLE ¼" THROAT
8 ¼" STAINLESS STEEL SUPPORTS FOR INNER CYLINDER. ALSO CONTAIN THERMOCOUPLE LEADS
9 LEADS TO FILAMENT ON INNER CYLINDER
10 INNER CYLINDER
11 B.&W. NO. 30 REFRACTORY BRICK
12 THERMOCOUPLE LEADS (ALUMEL-CHROMEL)
NOTE: NON-CROSS-HATCHED DENOTES STAINLESS STEEL

FIG. 1. GASIFICATION CHAMBER

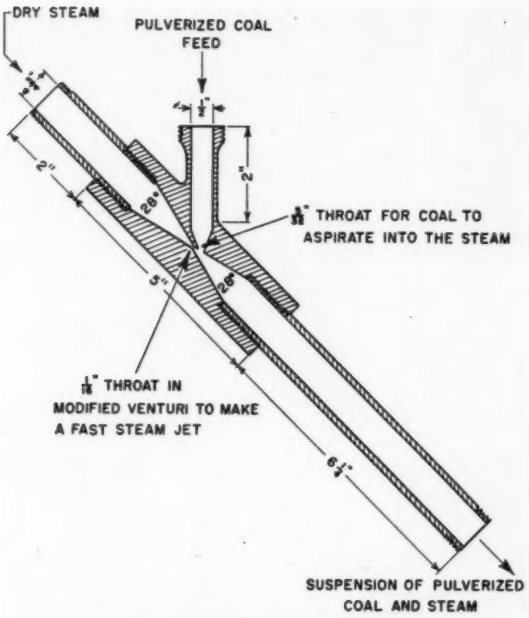


FIG. 2. VENTURI-TYPE COAL ASPIRATOR

There was no information regarding space requirements per pound of coal so that a substitution method was employed from the knowledge of the combustion rate for eastern bituminous coal.[8] A coal feed of approximately 2 lb per hour was assumed for design purposes, thereby requiring about 0.1 cu ft of space. The gasification chamber was constructed with slightly less volume than 0.1 cu ft. Curved pieces of thermal insulation were cut from B.&W. refractory brick No. 30 and plastered in place with a ground mixture of refractory brick, ball clay, cement, and water. The shell was constructed of two halves, each formed of 6-inch mild-steel heavy-duty pipe with a cap welded to one end and a flange welded to the other. The inner cylinder was made from a 6-inch length of 2-inch-diameter combustion tube refractory. This was supported by a stainless steel cradle composed of two rings–the bottom one forming a seat for the lower end of the cylinder. These rings were welded to two $\frac{3}{8}$-in. rods extending through the roof of the chamber. The rods were drilled and thermocouples were set up as shown in Fig. 1. All metal parts inside the reactor were made of stainless steel with the exception of a heated nichrome filament (18-gage). This filament was located on the inner surface of the refractory tube in order to insure proper ignition at all times. A stainless steel nozzle with a $\frac{3}{32}$-in. throat on a $\frac{3}{4}$-in. stainless steel pipe projected into the top of the inner cylinder.

Steam was decided upon as the vehicle for the pulverized coal suspension rather than oxygen mainly because of the danger of explosion in the hopper and feed line. It was also thought that the steam would heat the coal, thereby making it more reactive. Oxygen was used for the upblast through the annular space between the $\frac{1}{2}$-in. pipe and the $\frac{1}{8}$-in. tube. The $\frac{1}{8}$-in. tube was placed inside $\frac{1}{2}$-in. pipe in order to feed city gas into the chamber for heating it to starting temperature.

The problem of forming a suspension of pulverized coal in steam was troublesome. After some experimentation it was found that steam aspirated the coal which was fed into the throat of a modified venturi orifice shown in Fig. 2. The coal was fed angularly into the stream of steam at a point slightly downstream from the throat. The coal, however, had to be dry to have good free-flowing characteristics so that it could be easily introduced into the aspirator. The complete gasification unit is shown in Fig. 3.

Coal of size 100 mesh or finer, even though dried, did not feed well because of coking. Coal of size 35 mesh or coarser needed no drying other than air drying in order to feed well. A dried mixture of fine and coarser coal (20-mesh to 200-mesh and finer) was found to feed very well when the feed tube of the aspirator was vibrated.

Operation

The reactor, must be heated to 1000° C by passing city gas through the inner tube and passing air through the oxygen pipe. The nichrome filament, when it is heated red hot by electricity, ignites the gas. Enough oxygen is then turned on to sustain combustion. In order to avoid coking of the coal in the hopper due to steam wetting, the coal hopper is kept under pressure. Carbon dioxide is added to the hopper to equalize pressures and prevent steam from entering this part of the system. The vibrator is turned on, followed by the coal-feed screw. Both the carbon dioxide and steam must then be turned on simultaneously and quickly adjusted to their proper rates. Following this procedure the oxygen rate is increased to accommodate the coal entering the reactor. The city gas is then turned off.

The temperature in the reaction chamber should not be allowed to fall. It can be ascertained by the thermocouples located at various points in the reaction chamber and by the small pyrex window built into the wall of the reaction chamber. If the coal fails to ignite, the reaction will not be self-sustaining, and the temperature will fall. The red glow inside the chamber, as viewed through the window, disappears, and the chamber becomes dark. In this event the oxygen must be turned off immediately, the rest of the apparatus shut down, and the starting procedure repeated.

Table I shows results of a successful test run made

for two hours using Tono Coal from the Strain Mine. The coal had the following composition as found experimentally:

Proximate Analysis (By authors)		*Ultimate Analysis* (By Snyder and Swingle)[9]	
Moisture	17.0%	Hydrogen	5.5%
Volatile matter	33.2%	Carbon	74.1%
Fixed carbon	38.0%	Nitrogen	1.6%
Ash	11.8%	Oxygen	18.3%
		Sulfur	0.5%
		Heating value	12,920 Btu/lb

TABLE I

Pressure		Temperature		Flow Rate	
Item	Lb/Sq In Gage	Location	°C	Item	Rate
Hopper	8	Steam-coal suspension	185	Coal	11 lb/hr
Steam line	48	Top, inner cylinder	1110	Steam	17.7 lb/hr
Cyclone	0	Bottom, inner cylinder	1250	Carbon dioxide	3.5 cu ft/hr (s.c.)
Steam-coal suspension	6	Wall of upper ½ of chamber	430	Oxygen	11 cu ft/hr (s.c.)
		Wall of lower ½ of chamber	625	Washed gas	85 cu ft/hr (s.c.)

TABLE II
Screen Analysis of Original Coal

Mesh Size	%
20— 35	1
35— 48	9.2
48— 65	16.0
85—100	15.4
100—150	18.6
150—200	16.4
—200	24.4

TABLE III
Orsat Analysis of Product Gas

Component	In Reaction Chamber (%)	In Cyclone (%)	In Meter (%)
CO_2	46.3	46.5	47.7
CO	30.0	33.0	29.0
H_2	21.2	16.7	19.8
CH_4	2.5	3.8	3.5
O_2	0.0	0.0	0.0
N_2	0.0	0.0	0.0
H_2/CO	0.71	0.51	0.68

Table II shows the screen analysis of the original coal, and Table III, the Orsat analysis of the product gas. The carbon efficiency was calculated by dividing the carbon appearing in the product gas by the amount of carbon in the entering coal as calculated from the ultimate analysis. The carbon efficiency calculated on this basis was about 30 per cent.

Discussion

In spite of the fact that the gas produced was of poor quality and that carbon efficiency was low, the experiment was successful in operation. Coal particles could be seen rapidly passing upward through the window, indicating that the flow inside the generator was correct. The high carbon dioxide content

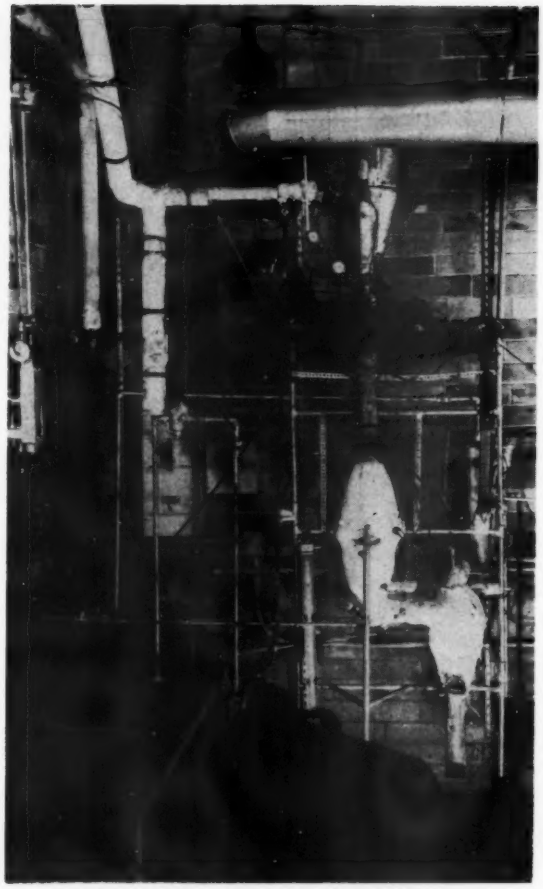


FIG. 3. COMPLETE GASIFICATION UNIT

was thought to be due in part to the following factors:

a) Insufficient thermal isolation caused high radiation losses. This required more carbon dioxide to be formed in order to maintain temperature in the chamber.

b) The low temperature of the entering steam-coal suspension as well as the low temperature of the oxygen caused carbon dioxide formation. Considerable heat would be required to increase the enthalpy of oxygen and steam to that of the reaction temperature at the expense of increased carbon dioxide formation.

c) An excessive steam rate caused the formation of extra carbon dioxide by requiring more combustion in order to heat the excessive amount of steam.

The ratio of the volumes of steam blast to the oxygen blast was approximately fifty, which amply

satisfies the requirements for good circulation as determined from the model equipment.

Conclusion

The complete gasification of Southwestern Washington coal is possible by the circulating suspension type processes. This type of process is best suited for the production of synthetic gas rather than fuel gas. If this process could be adapted to high-pressure gasification it probably would be applicable for fuel-gas manufacture.

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Nuclear Conference Held at Hanford

A conference on Nuclear Engineering was held at the Hanford Works of the Atomic Energy Commission at Richland, Washington, February 8, 9, and 10. In addition to staff members from the Commission and the General Electric Company, 22 faculty members from the University of Washington, Washington State College, Oregon State College, University of Idaho, and Montana State College attended. Representing the University of Washington were Dean Harold E. Wessman and Professors R. W. Moulton, A. V. Eastman, and B. T. McMinn. D. W. McLenegan, Manager, Technical Personnel Office, General Electric Company, Richland, who is also in charge of the in-service educational program at the Hanford Works, arranged the program which included papers, most of them presented by Hanford engineers and scientists, and an inspection trip of the Works.

The conclusions submitted in a report signed by the deans of engineering of the five institutions represented and endorsed unanimously by the Pacific Northwest Regional Committee of the ASEE, Dean Wessman, chairman, included the following:

1. The need for competence in physical science and fundamental engineering is greater (in the nuclear industry) than in most industries. . . . Many of the engineering problems stem very directly from physics, chemistry, and biology. . . . Engineers who can reason from fundamental data will be in demand.

2. These projects . . . call for the joint accomplishments of many people—teamwork in research, design, construction, operations, and between the several groups. Human engineering is of great importance.

3. The size and expense of constructing, operating, and maintaining these facilities call for the exercise of sound economic judgment. This is particularly needed among the engineers who have the physical comprehension of processes and their problems.

4. The range of scientific, engineering, economic, and operational problems is very broad. An undergraduate course cannot prepare a man in all these fields. This suggests continuing the fundamental training of engineers in the recognized major fields—chemical, metallurgical, mechanical, electrical, civil—rather than a composite course in nuclear engineering. . . .

5. In considering any special teaching towards the nuclear field, the undergraduate and graduate fields seem to call for quite different treatment. For undergraduate, many of the same basic subjects apply equally well to nuclear and to other industrial problems. This suggests that specialization towards the nuclear field be reserved largely for graduate study.

6. Due to security restrictions and to the special and expensive facilities involved, there is reason for continued technical study at plants such as Hanford, in parallel with the day's work. Such study can complement university graduate study, rather than compete. The critical review of such teaching by university authorities, with academic recognition reserved entirely to the universities, safeguards the standards and offers an opportunity for wide-spread educational service.

Fourth Northwest Conference on Road Building

R. G. HENNES
Professor of Civil Engineering

OVER 250 MEN, including 180 engineers from off campus, attended one or more sessions of the Fourth Northwest Road Conference held at More Hall, February 14-16.

Mr. William A. Bugge, Washington Director of Highways, was introduced by Dean Guthrie who welcomed the group to the University. Mr. Bugge opened the Conference with a tribute to the contributions made by preceding conferences to the technological development of road and highway organizations. These organizations now are better prepared than ever before to undertake highway work of a permanent character. The national emergency threatens to disrupt all highway construction programs, and it is possible that future circumstances may require more ingenuity and economy than ever before in developing those traffic arteries which are considered essential to the national defense. The problem is increased by the unprecedented growth in population which is common to all three Pacific Coast states. The natural resources of Washington assure that continued growth will magnify the highway problem in future years.

Wednesday afternoon was devoted to discussion of bituminous paving materials. Mr. F. S. Scott, research engineer from Wilmington, California, spoke on developments in the bituminous paving of light duty roads and streets. Mr. Carl Minor described the new program of stability testing with which he is concerned in his work at the Washington Highway Department's Material Testing Laboratory, and which has already led to considerable savings in the cost of highway construction. Mr. D. E. Stevens, of San Francisco, emphasized the importance of base courses, and the need for continued research on this essential element of the pavement structure.

On Thursday morning the first talk was given by Mr. Emmit Aston, Chairman of the Natural Resource Road Committee of the Pacific Logging Congress. Mr. Aston emphasized the importance of the logging industry to the economic well-being of the State, and urged that portions of the highway system be made available to heavier, and hence more efficient, logging trucks. Mr. W. A. Stancer, Pierce County Engineer, told of the increased maintenance charges imposed upon counties by intensive military use of local roads. Mr. Theodore Dec, of Washington, D. C., described the Maryland Road Tests on which he has been engaged and which have disclosed the extent of pavement damage inflicted by overweight truck loadings. Mr. Dec received his M.S. degree in highway engineering from the University of Washington in 1946.

Developments in the highway use of Portland cement concrete were described in the Thursday afternoon session. Mr. Robert Tobin said that structural engineers have a new constructional material in prestressed concrete, which permits fabrication of concrete members capable of withstanding tension as well as compression. Mr. T. B. Stone described the construction of a cement-treated base by the Washington Department of Highways. Dr. A. Allan Bates of Chicago, described the new laboratories of the Portland Cement Association. He emphasized the importance of basic research in problems involving many variables. In such cases the use of statistical methods and empirical tests cannot provide a reliable basis for predicting performance, and the study of fundamental properties becomes essential.

Friday morning was devoted to photogrammetry. Professor H. M. Chittenden provided the basis for discussion, with his presentation of theoretical considerations. Mr. Norman Thompson, of Los Angeles, described field methods and equipment, and his display of apparatus aroused much interest. Mr. Carl Berry completed the symposium with a talk on applications of photogrammetry to highway engineering.

The final session of the Conference started with a paper by Mr. W. L. Shannon on the use of porous concrete drains for landslide control. Dr. L. C. Wheeting of Washington State College explained the engineering uses of agricultural soils maps, which provide a surprising amount of valuable information for the highway engineer. The Conference closed with a plea by Mr. W. H. Landaas for the use of contract road construction under the conditions imposed by the present national emergency.

The *Proceedings* are now being edited for publication and may be obtained from the Engineering Experiment Station for $1.00. Copies of *Proceedings* for previous meetings are also available at the same price.

ROAD BUILDERS

Upper left *(left to right)*: C. Minor, F. S. Scott, D. E. Stevens, A. S. Wellborn, with the Hveem Stabilometer

Upper right: Prof. H. M. Chittenden

Center left: E. Aston, W. A. Stancer, Bob Glenn

Center right: Dr. A. Allen Bates, T. B. Stone, F. J. Barrett

Below: Prof. R. G. Hennes, W. A. Bugge, Prof. R. B. Van Horn

Lower photo courtesy SEATTLE TIMES

Mineral Industry Institute Held on Campus

The twenty-fourth annual Mineral Industry Institute was called to order on Thursday, February 15th at 1:30 p.m. by Professor Drury A. Pifer, Director of the School of Mineral Engineering. After a welcoming talk he introduced Dr. James I. Mueller, Assistant Professor of Ceramic Engineering, who presided at the afternoon session of the meeting.

The meeting opened with a showing of the movie, "Looking Through Glass." This was followed by a paper delivered by Larry Penberthy of the Penberthy Instrument Company, Seattle. His paper entitled, "Glass—Why and Where From," dealt with the various raw materials needed in the manufacture of glass and of the difficulties encountered.

The second paper, "Sources of Silica for the Soluble Silicates," was presented by Dr. T. K. Cleveland, Director of Research for the Philadelphia Quartz Company of California. Dr. Cleveland pointed out that the glass sands utilized by plate and container manufacturers were not suitable for use in soluble silicates because of their high content of aluminum oxide. He further pointed out that, although the sources of sodium carbonates were limited, his company hoped to have sufficient reserves to hold them over any emergency. He concluded with some very interesting observations on the special processes required to manufacture the product known to us as "water glass."

The third speaker, Mr. Hal J. Kelly of the Northwest Experiment Station, U. S. Bureau of Mines, spoke on some research work being done at present by the Bureau on the fluxes available in the Dry Lake deposits of central Washington. He indicated that the supplies of these salts are very limited, and that it would be hardly economically feasible to develop them commercially.

After a short intermission, a film on the manufacture of refractory materials was shown through the courtesy of Gladding-McBean & Company. Following this, Mr. E. H. Whitney, production superintendent of the Northern Division of Gladding-McBean spoke on the manufacture of refractories in the Northwest and the problems peculiar to this area. He said that, contrary to local belief, there are sufficient quantities of high-grade refractory clays available, but he added that there is need for a good plastic refractory clay.

The final paper on the program was delivered by J. Phillip Purdy, Jr., of the State Department of Mines and Geology on the geology and possibilities of refractory clays in the state.

The evening meeting was held in collaboration with the Pacific Northwest Section, American Ceramic Society, and the North Pacific Section, AIME, at the Hub. After a short business meeting, the chairman, Allen Erickson of Northwestern Glass Company, introduced the guest speaker, Dr. Louis Koenig of the Stanford Research Institute. Dr. Koenig spoke on raw materials that are critical during the present emergency, and how the western states are in an advantageous position to capitalize on the development of marginal deposits of these materials. He listed chromite and asbestos as the chief of these materials available in the Northwest and concluded with some very interesting details on the application of ceramics in the form of cermets and refractory coatings in jet and rocket engines.

There were a total of 100 registrants at the Institute, from Canada, Montana, Oregon, Washington, and California.

LIGNIN PROCESS TO BE DEVELOPED COMMERCIALLY

The Research Corporation of New York has undertaken the commercial development of the process for treating wood by means of triethylene glycol as first described in last July's issue of *The Trend*. This process for the separation of wood into pulp and lignin was developed by Dr. Bror L. Grondal, Professor of Forest Products, and Dr. Piotr Zenczak, Research Associate. Dr. Zenczak, a Polish refugee who was confined to a German concentration camp during the war, came to the University three years ago and has carried on his research under Project No. 16.

By the new process, according to Dr. Grondal, lignin, hitherto considered a waste product in the manufacture of pulp, may prove to be a more valuable product than the pulp itself. In addition to useful adhesive qualities, the lignin complex offers plastic possibilities and contains many of the compounds now obtained from coal tars.

Under its agreement with the Research Corporation, the University will be assigned the largest share of profits from the process, with the patentees and Research Corporation receiving smaller shares. Arrangements are being made for the installation of a pilot plant to test the process on a practical basis.

MICROWAVE RADIO LINKS FOR ISLAND COMMUNICATION

H. M. SWARM
Instructor in Electrical Engineering

A. E. HARRISON
Associate Professor of Electrical Engineering

H. M. Swarm

Many microwave radio point-to-point installations, supplanting the more conventional open-wire or cable lines, have been made in recent years. This has been particularly true where the communication points are separated by rugged mountain terrain or by water, as in inter-island communication systems. Microwave radio links offer many advantages over other systems for these applications.

One advantage is that the microwave equipment is concentrated at a small number of locations, thus simplifying the installation and maintenance problems. An attractive advantage of microwave radio links is the additional communication channels available when expansion is desired. Since most microwave links employ time multiplexing in their modulation systems, additional channels are quite readily available with very little additional equipment.

The final decision between a microwave radio link and other systems of point-to-point communication is based on an economic study of the particular application under consideration. Surprisingly enough, the complexity of the terminal equipment in a microwave radio link is quickly compensated if very many channels are desired. The Bonneville Power Administration has published data[1] which show that a microwave radio link may be the most economical if more than four channels are required.

In order to evaluate the factors influencing the choice of a microwave radio installation, it is necessary to understand the unusual properties affecting the propagation of these waves. It has long been known that high-frequency radio waves exhibit quasi-optical properties, but exceptions seem to be the rule at the frequencies used for TV and FM broadcasting. The optical behavior becomes more pronounced above 1,000 megacycles, and optical properties such as shadows, refraction, diffraction, and reflection must be considered.

[1] R. F. Stevens and T. W. Stringfield, "Microwave Applications to Bonneville Power Administration System," *Electrical Engineering*, Vol. 70, No. 1, pp. 29-34.

A. E. Harrison

Refraction of microwaves may be utilized to partially overcome the effects of shadows. The moisture content of the air normally decreases with height. As a result, the waves near the surface of the earth travel more slowly than in the higher atmosphere and the wavefront is slowly directed back to the ground. The actual path is curved, and this effect is frequently included in an analysis by plotting paths on profile maps drawn with a radius of ⅓ the actual radius of the earth. Thus paths which are actually curved in space can be drawn as straight lines. However, recent practice tends to avoid reliance on refraction because a greater factor of safety is required to eliminate trouble from diffraction and reflection.

Diffraction by obstacles such as hills, trees, houses, or any abrupt variation of dielectric constant causes more trouble than in optics because the microwaves are so much longer than light waves. Stated in optical terms, the distance to the closest obstacle anywhere along the path should be greater than the radius of the first Fresnel zone at that point on the path. This means that a triangular path from the transmitter to the obstacle, then to the receiver, must be more than one-half wavelength greater than the direct path between transmitter and receiver. For long paths the vertical clearance must be several hundred feet at the midpoint of the path and decreases in an elliptical manner to one-half wavelength at either antenna.

Reflections from a plane surface, such as the surface of the water, must also be considered. If the reflecting surface is stationary and has a constant reflection coefficient it would be possible to locate an antenna at a point where the reflected wave adds to the direct wave. Usually, because of the wind or tide, the reflecting water surface is continually changing and produces severe fading.

It is often necessary to use diversity reception to minimize the effect of fading. Two types of diversity

reception may be used. Space diversity reception, in which one receiver antenna is located at a greater height than a second receiver antenna, is the first and more common method. Frequency diversity reception, in which the desired information is transmitted and received on two different frequencies, is the second method and often more expensive. In either type of diversity reception the antenna receiving the greatest instantaneous signal intensity is used in obtaining the desired information.

Another microwave propagation property known as "trapping" must be considered, particularly on over-water paths. "Trapping" is caused by atmospheric conditions associated with a temperature inversion when the temperature of the air actually increases with height over a limited range. This condition produces a highly efficient propagation duct similar to a wave guide in space. These ducts can be used to obtain transmission over water beyond the line of sight in certain instances where their formation and location can be reliably predicted. More frequently it is a hazard which causes severe fading on a direct path and the "trapped" signal may be diverted completely so that communication is impossible.

In summarizing, the considerations for a good microwave path are as follows:

(a) The distance should be short, preferably less than 30 miles; even shorter paths are desirable over water.

(b) Clearance between the line of sight path and all obstacles in any direction should be greater than the radius of the first Fresnel zone.

(c) Vertical space diversity reception is desirable for minimizing fading.

The ability to form microwaves into narrow beams is another important factor in the design of microwave radio links. This property affords some advantages of secrecy, but the principal consideration is the saving of power because the energy is directed toward the receiver and a much larger fraction of the transmitted energy is utilized. In other words, a microwave antenna utilizing a paraboloidal reflector has a large power gain; consequently it is not necessary to use a very high power transmitter. This factor offsets the fact that the simpler microwave sources are essentially low-power devices.

For a given diameter reflector, the antenna gain increases with frequency and the angular width of the radiated beam decreases. With very narrow beams the supporting tower must have great rigidity to prevent loss of signal during stormy weather. Quite often a choice of a lower frequency or a smaller reflector and, hence, greater beam width, is more economical than increasing the tower rigidity.

A preliminary survey made last summer for the West Coast Telephone Company will be used as an example to illustrate the application of these principles to the selection of sites for a microwave relay link. Additional communication channels were desired between the Everett telephone exchange on the mainland, and the exchanges in Langley and Oak Harbor on Whidbey Island. The survey consisted of a study of the Geological Survey maps of the area, a reconnaissance trip to investigate tentative sites and a field test with 10,000-megacycle equipment to correlate the measured field strength with the predicted field strength for a path. The following paths were selected for investigation:

(1) a path from downtown Everett to a point on the east side of Whidbey Island, a few miles south of Langley,

(2) a path from the hill east of Mukilteo to Blowers Bluff across the bay south of Oak Harbor,

(3) a path from downtown Everett to a relay station on Camano Island and from this relay station to a hill behind the telephone company office in Langley and also from the relay station to a hill about ½ mile north of Oak Harbor.

Path profiles as illustrated by Fig. 1, were plotted from data obtained from the topographic maps, using the standard factor ⅓ times the earth's radius. Profiles usually do not indicate the height or location of trees which may be obstacles in the paths, a factor of importance in the choice of tower heights.

Path (1), from Everett to the bluffs south of Langley, is the shortest path and has good clearance above the water. Reflections from the water are inevitable but "trapping" may not be serious on a short path such as this. One disadvantage of this path is that the terminal equipment on Whidbey Island would have to be located at some distance from Langley.

One of the possibilities for a direct link to Oak Harbor would be path (2) from a 550-foot hill east of Mukilteo to Blowers Bluff. This path is shadowed from water reflections by a point of Camano Island, but reflections from the water are possible between Camano Island and Blowers Bluff for a distance of about 5 miles. It is probable that field tests over a period of time would be desirable before making a definite recommendation on this path.

An Everett to Oak Harbor or Langley link with a relay station on Camano Island, path (3), has certain advantages. The terminal equipment would be close to the point of use at each end for both lines. The

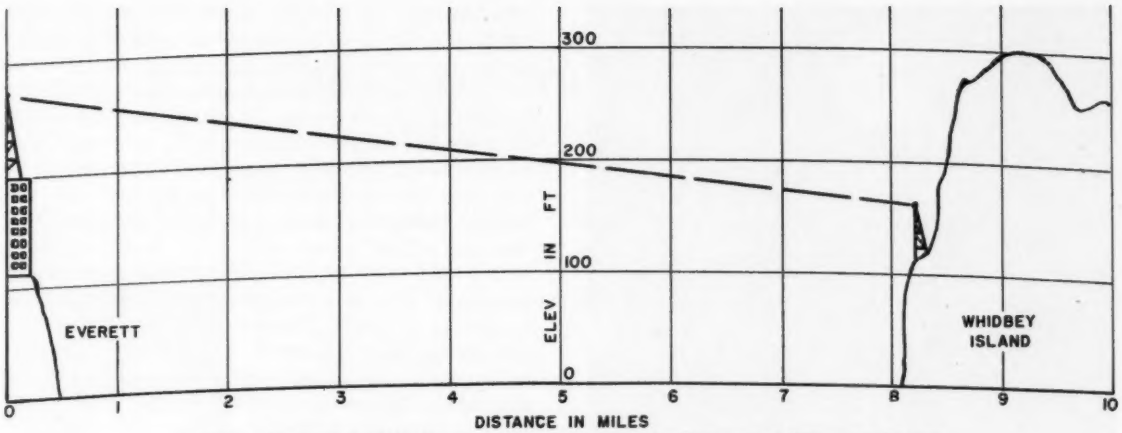

FIG. 1. PROFILE MAP OF PATH (1) FROM DOWNTOWN EVERETT TO WHIDBEY ISLAND

relay station located on the 400-foot ridge of Camano Island would utilize the length of the Island to shield the Everett-Oak Harbor paths from water reflections and "trapping." The relay station-to-Langley path has a length of approximately 9½ miles with 6½ miles over water. This path is very similar to path (1) with the distance over water slightly less and with greater clearance.

Path (1) between Everett and the bluffs south of Langley was chosen for a field test. The transmitter was located on the roof of the Medical-Dental building in Everett. This building is one of the highest in Everett and is situated only two blocks from the telephone company office. The receiver was located on Whidbey Island on the bluffs south of Langley. The portable receiving equipment, mounted in the rear of a car, is shown in Fig. 2.

The equipment for the field test consisted of a type 2K39 klystron transmitter operated in the 10,000-megacycle amateur band and a calibrated FM receiver. The transmitter had a power output of 300 milliwatts with an antenna power gain of approximately 1,500. The receiver utilized a modified type 723AB klystron as a local oscillator with a type 1N23 crystal mixer. The output of the mixer was connected to a modified aircraft-type FM receiver tunable from 27 to 39 megacycles. The modifications consisted of a microammeter inserted in the limiter circuit as a crude indication of field strength and the insertion of the d-c voltage from the FM discriminator in series with the reflector voltage of the 723AB local oscillator to obtain automatic frequency control. The latter feature overcame the instability of both klystrons and permitted an accurate reading of the limiter current.

Calibration of the receiver consisted of measuring the limiter current as a function of the input in microvolts from a signal generator connected directly to the aircraft-type FM receiver and also in terms of the microwave power input to the crystal mixer.

The calculated microwave power available at the microwave mixer is given by the following expression:

$$P_r = \frac{P_t \times \text{Antenna Power Gain} \times \text{Antenna Area}}{4\pi d^2}$$

where P_r is the power in watts at the receiver, P_t is the power at the transmitter, d is the distance between transmitter and receiver in feet, the antenna gain refers to the transmitting paraboloid, and the antenna area in square feet refers to the receiving paraboloid.

The calculated field strength using the foregoing equation was 0.038 microwatts, and from the receiver calibration the limiter current should have read 5.5 microamperes. The measured current for the best adjustment of the equipment was 7 or 8 microamperes. The difference corresponds to an increase in power by a factor of three. The discrepancy can be attributed to errors in calibration or aiding reflections. These results are definitely within the limits of error for the test.

Evidence of reflections from the water was indicated by a much wider apparent beam in the vertical direction than in the horizontal direction. There was no observable effect of zones of interference between the direct and reflected signals, although this factor was not investigated carefully since it was not convenient to raise and lower the receiving antenna.

After a study of the advantages and disadvantages of the various paths, an economic study should be undertaken. Many times the economic study will conclusively show the most practical path. Once the

FIG. 2. H. M. SWARM AND ROBERT PERRY WITH MOBILE EQUIPMENT USED AT THE WHIDBEY ISLAND RECEIVING SITE

Power supplies and FM receiver are shown mounted in the trunk of the car. The portable tower with receiving paraboloid antenna is mounted on the rear bumper.

Photo courtesy EVERETT DAILY HERALD

path has been determined a much more detailed field test is in order. This test should be made with equipment that can be conveniently raised and lowered vertically to check Fresnel zone maxima and minima as calculated from theory. Diversity receiving equipment should then be installed with recorders connected to indicate signal strength. The percentage of time that the circuit is not operable and also the average fading to be expected may be calculated from data for several weeks, although a period of more than a year may be necessary if the possibility of "trapping" is to be considered. In some cases circuit economics or short distances may make elaborate tests unnecessary. However, where the circuit must be as nearly 100 per cent continuous as possible, the additional information gained from the second field tests is definitely worthwhile.

ACKNOWLEDGMENTS

The writers wish to thank the West Coast Telephone Company for permitting the use of their communication problem as a typical example. Acknowledgments are also due graduate students John L. Bjorkstam and Robert E. Perry for their assistance in making the field test.

AERONAUTICAL RESEARCH BULLETIN TO APPEAR SOON

Investigations in Aeronautics from the Department of Aeronautical Engineering (Bulletin No. 118) will be off the press in May. Edited by Prof. R. M. Rosenberg, it will contain the following papers: "The Generation of Airfoil Shapes in Subsonic Compressible Flow," R. Mark; "The Laminar Boundary Layer in Accelerated Compressible Flow," H. A. Stine; "Effects of Variable Viscosity and Thermal Conductivity on the High-Speed Couette Flow of a Rarefied Gas," T. C. Lin; "Rational Design of Metering Pins in Oleo Struts," H. P. Durand and R. M. Rosenberg; "Aileron Flutter in a Single Degree of Freedom," K. P. Abichandani and R. M. Rosenberg; "Periodic Solutions of a Nonlinear Differential Equation," R. M. Rosenberg and A. J. Wang; "The Influence of Axial Torques on the Critical Speeds of Uniform Shafts in Self-Aligning Bearings," R. M. Rosenberg; "An Instability Problem Arising in Uniform Cantilevered Struts," H. C. Martin; "An Observation Regarding the Deflections of Uniform Swept Cantilevered Plates," H. S. Gursahaney and H. C. Martin; "The St. Venant Torsion Problem for the Hyperbolic Airfoil Cross Section," T. C. Lin and L. G. Whitehead, Lecturer at the University of London; "The St. Venant Torsion Problem of Cross Sections Consisting of One Loop of the Hyperbolic Limacon," T. C. Lin and H. T. Yang.

ELECTRODE-ELECTROLYTE TEMPERATURE DIFFERENTIALS*

T. R. BECK
Research Fellow, Engineering Experiment Station

G. L. PUTNAM
Research Associate, Engineering Experiment Station

T. R. Beck

ABSTRACT

The temperature difference (ΔT) between an operating electrode and the electrolyte in which it is immersed was studied. The temperature difference is the result of heat developed at the electrode due to overvoltage and to the difference beween the free energy and the heat of reaction. Data are presented for ΔT of a smooth platinum-iridium anode in 40 per cent perchloric acid in the current density range, 4.5 to 180 amperes per square decimeter, and temperature range, —45° to +45° C. The ΔT data correlate linearly with viscosity of the electrolyte.

G. L. Putnam

Physical chemists and chemical engineers have usually assumed that the temperature of an operating electrode is the same as that of the electrolyte in which it is immersed. In general, however, heat is liberated or absorbed at an operating electrode and the dissipation of this heat through the electrolyte film adjacent to the electrode surface causes a temperature difference to develop. This heat effect may arise in two ways: (1) reversible heat effect due to difference in heat reaction and the free energy of reaction, and (2) irreversible heat effect due to overvoltage.

The heat of reaction and free energy of an electrolytic reaction are related by the equation:

$$\Delta Q = -nFE - \Delta H = -nFT\left(\frac{\partial E}{\partial T}\right)_P.$$

The total heat liberated at the surface of an irreversible electrode for the passage of n faradays is

$$\Delta Q' = -nFT\left(\frac{\partial E}{\partial T}\right)_P + n\eta F.$$

There will be additional heat effects in the electrolyte due to electrolyte resistance and concentration polarization. If $\left(\frac{\partial E}{\partial T}\right)_P$ for the electrode reaction is negative, then heat is always liberated at the electrode, and if $\left(\frac{\partial E}{\partial T}\right)_P$ is positive, then heat may be either liberated or absorbed, depending on the relative values of the two quantities. In the cases of the latter type, heat may be absorbed at low-current densities and liberated at high-current densities due to increase in overvoltage. In the case reported here the irreversible heat controls.

That any voltage applied to a cell in excess of the reversible decomposition potential is used in liberating heat was shown in early (1913) work by J. W. Richards,[1] who measured the electrical energy input to a cell electrolyzing water, the cell being operated in a calorimeter. Assuming ΔH and ΔF were equal for the decomposition of water, Richards showed that, within his experimental error, the electrical energy in excess of that required for the decomposition of water was liberated as heat.

Measurements of the temperature of operating electrodes have been confined to systems of very low overvoltage and at low-current densities. Bruz,[2] for example, measured the temperature of nickel, lead, silver, bismuth, cadmium, zinc, and copper electrodes in solutions of their ions to determine the entropy of the ions. In order to maintain essentially reversible conditions, he operated at very low current densities.

Tarasov[3] rather recently measured the temperature difference between an operating electrode and its electrolyte. He used 0.05 to 2.0 N. copper sulfate solution and current densities of 1.0 to 10 amperes

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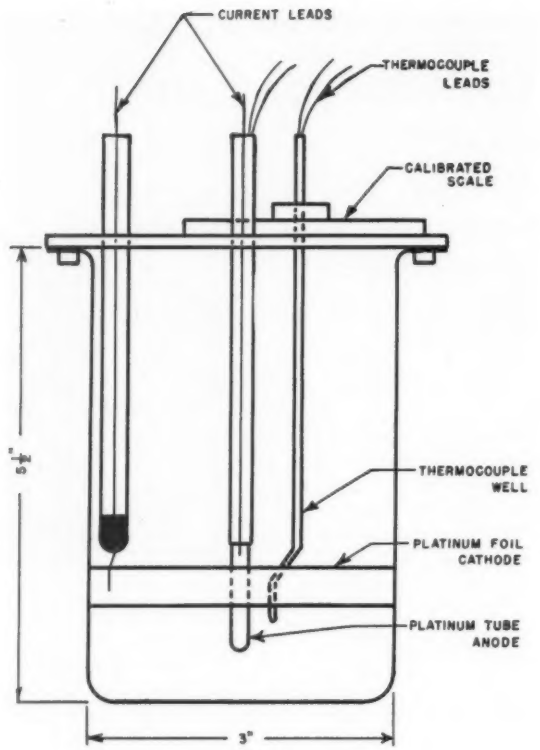

FIG. 1

per square decimeter. His electrode was a thermometer bulb silvered and plated with copper. The temperature differences amounted to 0.2, 0.5, and 0.95° C for current densities of 2, 4, and 6 amperes per square decimeter, respectively. In this system the electrodes have low overvoltages, however, and most of the heat would be from the reversible heat effect.

Experimental

Apparatus. The cell was a 500-ml Berzelius beaker with a ¼-in. thick "Transite" cover (Fig. 1) impregnated with "Tygon Clear" lacquer. The anode consisted of a 0.301-cm diameter tube of composition 95 per cent platinum and 5 per cent iridium, 2.34 cm long and sealed to a glass tube mounted in the "Transite" cover axially to the cell. The lower end of the anode tube, sealed with a glass bead, was filled with mercury to make electrical connection. The cathode was a ½-in. wide strip of 0.001-in. platinum foil. Electrical connection to the cathode was made through a No. 21 gage platinum wire spot-welded to the cathode and sealed in a glass tube with a mercury connection.

Temperatures were measured with copper-constantan thermocouples and a Leeds and Northrup

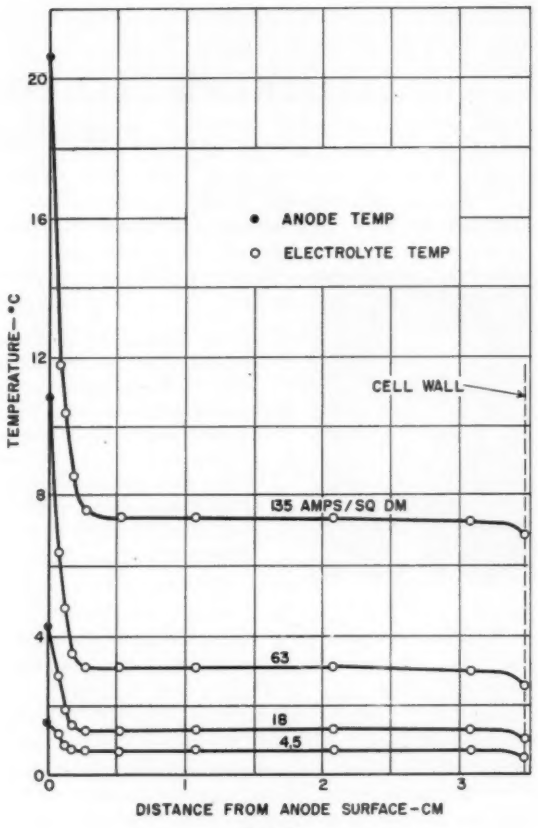

FIG. 2

Portable Precision Potentiometer Model No. 8662. Anode temperatures were measured by a thermocouple in the mercury pool within the anode. Electrolyte temperatures were measured by a thermocouple in a 1.5-mm outside diameter glass thermowell. The thermowell was mounted on a carriage which slid along a calibrated scale attached to the "Transite" cover, permitting measurement of electrolyte temperature as a function of distance from the anode. A third thermocouple was used to measure the temperature of the constant temperature bath in which the cell was placed.

Because of its interest in this laboratory in connection with the formation of ozone,[4] the electrolyte used was 40 per cent perchloric acid. Anode overvoltages with perchloric acid are higher than with sulfuric acid.[5]

Procedure. The cell was operated at current densities of 4.5, 9, 18, 36, 54, 90, 135, and 180 amperes per square decimeter at bath temperatures of 40°, 25°, 0°, –20°, and –45° C. Water baths were used at 40° and 25° C, an ice bath at 0° C, a constant

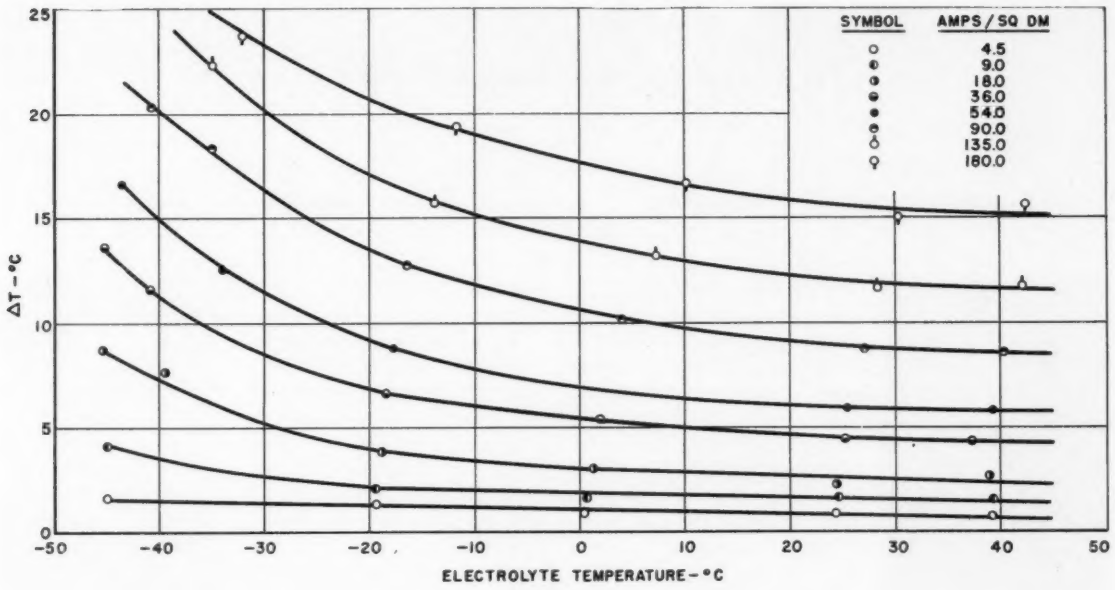

FIG. 3

temperature refrigerated antifreeze bath at –20° C, and calcium chloride-water eutectic mixture cooled with dry ice to obtain –45° C. At a given current density, the cell was allowed to operate for a sufficient length of time to reach thermal equilibrium before temperatures were recorded. This resulted in higher electrolyte temperatures for the higher current densities at each bath temperature.

Discussion of Results

Electrolyte Temperature Gradient. When the axis of the 1.5-mm diameter thermowell was more than 2 mm from the anode surface, the temperature difference was constant, indicating that the film thickness was of the order of 2 mm (Fig. 2). Temperature versus distance data were taken only for the case of the cell in the ice bath because of the difficulty of holding the cell at constant temperature for long periods of time at the lower temperatures. The temperature difference ΔT is defined as the difference between the anode temperature and that of the main body of the electrolyte.

Effect of Electrolyte Temperature and Current Density on ΔT. A plot of ΔT against electrolyte temperature with current density as a parameter is shown in Fig. 3. The ΔT value increases as expected with current density due to greater heat liberation. The ΔT also increases with lower electrolyte temperatures. This, as we shall see hereafter, can be correlated with increase in viscosity of the electrolyte.

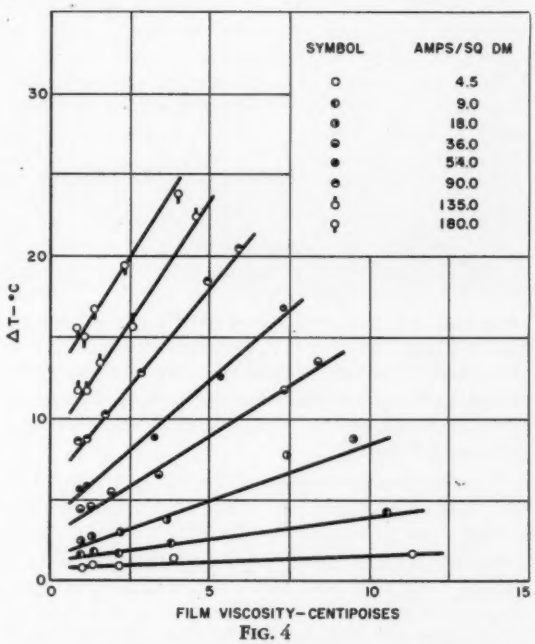

FIG. 4

Thus it is clearly shown that ΔT may become appreciable in the range of current densities used in industrial electrochemistry. This means that in temperature-sensitive electrochemical reactions such as ozone production,[4] it is not enough to specify the temperature of the electrolyte because the tempera-

(Continued on page 32)

ON STRESSES IN A TIMBER TRUSS JOINT

DAVID C. T. LIU
Graduate Student in Civil Engineering

S. SERGEV
Professor of Engineering Mechanics

D. C. T. Liu

The stress field at and in the vicinity of the cuts in joints encountered in trusses made of solid wood members is complex. Without elaborate investigation, one can conclude that there are points of stress concentration due to discontinuities in the member and improper contact between the members. If wood were an isotropic material and somewhat brittle, these local disturbances might have produced dangerous consequences. But, as is well known, wood has a large time-yield property which helps to redistribute the stresses and diminish those at points of concentration. It was decided that despite these favorable factors, a more intelligent approach to design of joints would result if the stress pattern in an isotropic material were known and points of stress concentration located.

To answer some of the questions which arise in design, a photoelastic study of a typical joint encountered in practice was made. (See Fig 1.) To avoid complications, the tension rod used in actual designs was replaced by a roller, permitting restriction of the problem to two dimensions. By similitude, the dimensions and forces on the model were determined from an actual design. The final model was made of bakelite BT 61-893.

For a pilot test a model of Columbia Resin CR39 was used. This plastic is rather brittle and has low strength. As a consequence, the chord member under a moderate force actually failed in tension along a section nearly in line with the vertical cut. Final observations indicated that this section followed the principal stress trajectory, with the incipient failure at the 90° corner where high stress concentration existed.

The pilot test indicated that a small radius at the 90° corner in the chord to reduce the stress concentrations was desirable. A model of bakelite, BT 61-893, gave good results. However, the comparatively long time required to make the model caused time-edge effect to occur which obscured the results at the boundaries. From the isoclinics (locus of constant orientation of principal stresses) stress trajectories were drawn. This was not a simple procedure because isoclinics were not everywhere distinct, and resort to continuity was made.

S. Sergev

Some of the significant observations resulting from this study are as follows:

1. Stresses in the chord and diagonal members at points one width of the member away from the cut can be estimated by the elementary theory.
2. The tensile stress in the chord at the 90° corner is approximately 4 times greater than the average stress in the chord, based on net area.
3. The compressive contact stresses on the vertical cut in chord and diagonal are high.
4. Contact stresses depend on the fit between the members.
5. Contact stresses depend on the angle between the chord and diagonal. Any deviation from the correct angle produces stress concentrations at the cut.

It is well established that the difference between the principal stresses, usually denoted by $p—q$, is immediately known from the photograph of the fringe orders and the model fringe value. (The model fringe value is easily found by a simple laboratory test.) The determination of $p + q$ is more involved, but, once this sum is known everywhere in the model, normal and shearing stresses at any point can be easily found. At a free boundary one of the principal stresses is known, the other then represents the normal stress tangential to the boundary. The maximum shearing stress is one-half of this stress. Usually the maximum stresses occur at a free boundary and it is this fact that enables one to report, very quickly, on the state of stress in a new design. Changes in design can be made, and their influence on the state of stress

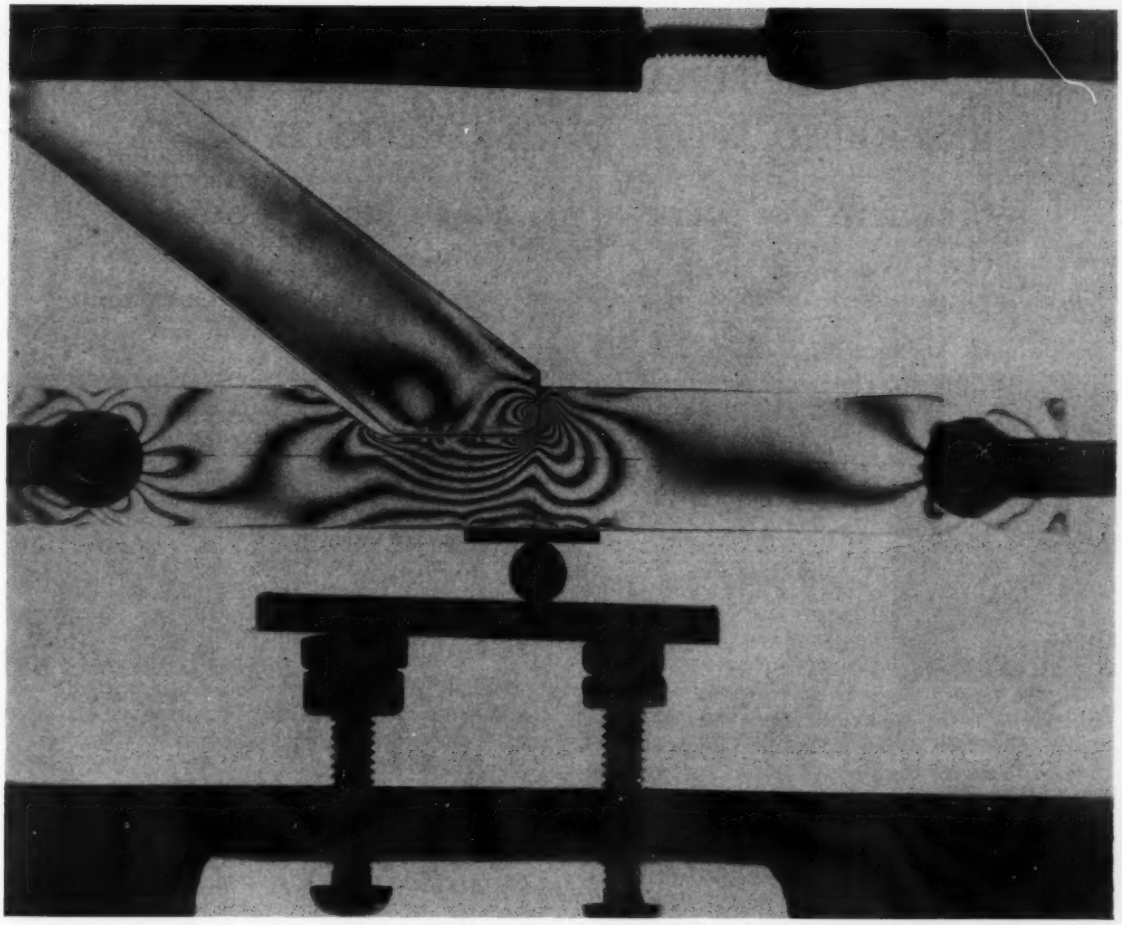

FIG. 1. PHOTOELASTIC STUDY OF A TYPICAL JOINT

noted. Herein lies the principal advantage of the photoelastic method, which produces results when analytical methods become intractable.

Some calculations were made to determine the stresses in the chord, but no attempt was made to describe the stress field completely until the control of loading and the determination of isoclinics were improved. Work is now in progress on both of these problems. The new method of loading will have one applied force which can be varied—all other forces will have immediate response, and be automatically regulated. Varying the load may give better determination and definition of the isoclinics. If this procedure fails, the isoclinics will be photographed under a constant load with the films over-exposed.

The determination of $p + q$ for the problem at hand will be made by the numerical solution of the Laplace equation:

$$\frac{\partial^2}{\partial x^2}(p+q) + \frac{\partial^2}{\partial y^2}(p+q) = 0.$$

Then it will be possible to give a complete description of the stress field at and in the vicinity of the joint.

"The desirability of research in colleges and universities is generally recognized, but the idea that research is an essential feature of a true university is not always accepted. Extension of the frontiers of knowledge is as necessary a function of the university as the teaching of young people. A 'community of scholars' does not make a university unless the scholars are creative scholars; teachers who limit their activities to the collection and dissemination of facts may serve a purpose (as does a gramophone record), but they are not of the stuff that makes a university. . . . Creative teachers are needed to inspire the young to creative effort."—T. K. Sherwood, Dean of Engineering, M.I.T., in *Chem. and Engg. News*, Am. Ch. Soc., Feb. 13, 1950.

SLIP OF STRUCTURAL STEEL DOUBLE-LAP JOINTS ASSEMBLED WITH HIGH-STRENGTH BOLTS*

PART I. EFFECT OF BOLT TENSION AND FAYING AREA UPON SLIP

D. R. YOUNG
Research Fellow, Engineering Experiment Station

R. A. HECHTMAN
Associate Professor of Structural Research

D. R. Young

Introduction

This report describes 23 tests of plain-carbon structural steel double-lap joints assembled with high-strength steel bolts. The test program, which was conducted in the Structural Research Laboratory of the Department of Civil Engineering, was designed to investigate the effects upon slip of the faying area and the tension in the bolts. All joints were tested in tension. The relative movement, or slip, of the lap plates with respect to the center plate was measured at various increments of load. The bolt tensions at the beginning of the tests and the loads at the first major slip being known, the nominal coefficients of friction at the first major slip could be computed.

TABLE I

PROGRAM OF TESTS

Spec. No.	Type of Specimen	No. of Bolts	Faying Area per Bolt sq in.	Bolt Tension Kips
Effect of Bolt Tension upon Slip				
13-15B	C	4	32	45
37-39				36
31-33	C4	4	28	24
57-59				36
Effect of Faying Area and Net Tensile Section upon Slip				
10-12B	C1	4	18	45
13-15B	C		32	
16-18	C2		50	
19-21	C3		72	

These coefficients afford the best method of comparison for specimens with different qualities.

Part II of this paper, which will cover the effect of the surface conditions of the faying area upon slip, will appear in the next issue of *The Trend*.

R. A. Hechtman

Tests and Test Methods

The program of tests is given in Table I. Figure 1 shows the types of double-lap joints that were used. The bolt holes were drilled through the three plates in one operation. The holes were $1\frac{3}{64}$ inches in diameter. Since the test holes were $^{63}/_{64}$ inch in diameter, a clearance of $\frac{1}{16}$ inch was obtained in the bolt holes. The faying surfaces were wire-brushed to remove loose mill scale. Grease or other foreign material was removed with carbon tetrachloride and clean rags. Semi-killed plain-carbon structural steel meeting ASTM Specification A 7-49T was used for all specimens.

The test bolts were manufactured from SAE 4140 steel with an ultimate tensile strength of 180,000 to 200,000 psi. This high-strength steel was chosen, rather than a steel meeting ASTM Specification A 325, commonly used for this purpose, so that the tensile stresses at the root of the threads would not exceed the proportional limit. Each bolt was individually calibrated to determine its elongation under tension. When the bolts were tightened, the desired tension was obtained by measuring their elongation during tightening. The bolts were inserted into the holes of the specimen with one washer under the head and one under the nut. The washers were 1 in. by $\frac{1}{16}$ in. in size and surface carburized $\frac{1}{32}$ in. deep.

All specimens were tested in tension. The load

*Abstracted from the thesis submitted by D. R. Young for the degree of M.S. in Civil Engineering, 1950.

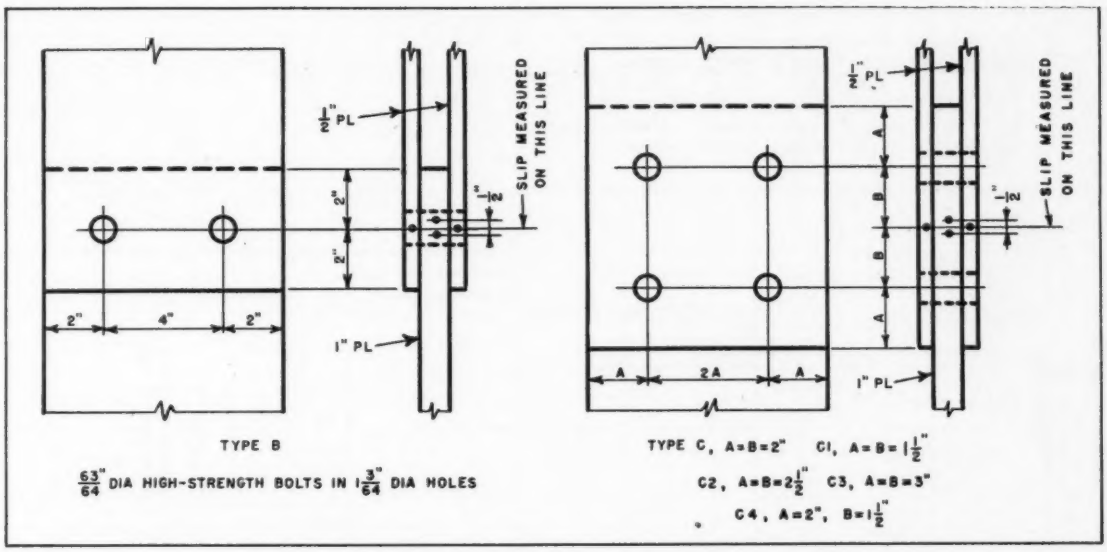

FIG. 1. TYPES OF DOUBLE-LAP BOLTED JOINTS USED IN TESTS

was applied slowly, slip readings being taken at regular intervals as well as immediately after every major slip. The test was discontinued shortly after the bolts came into full bearing on the plates. Upon completion of the test, the specimen was disassembled. The residual tension in the bolts was determined by the relaxation method.

Data of Tests

1. ***Comparison of Nominal Shear in Bolts and Average Slip in Bolted Joints.*** When load was applied to a specimen, there was at first no significant amount of slip in the joint. As the load was increased, a very small amount of slip and elastic deformation was indicated by the gages. A load was eventually reached at which the shear between the plates overcame the frictional resistance to slip. The plates then slipped with extreme rapidity. This first large slip is referred to as the first major slip. The load was again increased until further slipping occurred, and eventually the bolts came into full bearing on the plates. Figure 2 compares the nominal shear in the bolts and the average slip in the joint for a typical series of tests, the nominal shear being plotted vertically and the slip horizontally. The nominal shear is defined as the load applied to the specimen divided by the total gross shearing area of the bolts.

The data of the tests are summarized in Table II. The faying area per bolt is defined as the area of overlap of the lap plates with the center plate divided by the number of bolts. Deductions were not made for the bolt holes in these computations. All the tests reported in Part I were made on specimens with mill-scale faying areas. Column 5 gives the average of the tensions which were applied to the test bolts. Columns 6 and 7 list the nominal shear on the bolts at loads corresponding to the first major slip and full bearing of the bolts on the plates. Column 8 gives the average tensile stress on the net section of the specimens at the load corresponding to the first major slip. The coefficient of friction, as given in the last column, was computed as the ratio of the load at the first major slip to the initial clamping force on the joint. The average coefficient of friction at the first major slip for each group of identical specimens is given in parentheses below the group.

2. ***Effect of Bolt Tension upon Slip of Bolted Joints.*** The average of the nominal coefficients of friction at the first major slip for each group of tests is shown in Table II. For the Type C specimens at 45 and 36 kips per bolt, they were 0.36 and 0.37 respectively. They were 0.36 and 0.37 for the Type C4 specimens at 24 and 36 kips per bolt respectively. This constancy is demonstrated in Fig. 3, where the nominal shear on the bolts at the first major slip is compared with the average tension in the bolts before the test. A straight line was drawn through the test points.

Figure 3 was based on the tension in the bolts before the tests. When the bolt tensions were measured after the test, it was found that they had decreased. Stresses above the yield point in the vicinity of the bolt holes had brought about a contraction of the plate thickness which reduced the bolt tension. The average tension remaining in the test bolts at

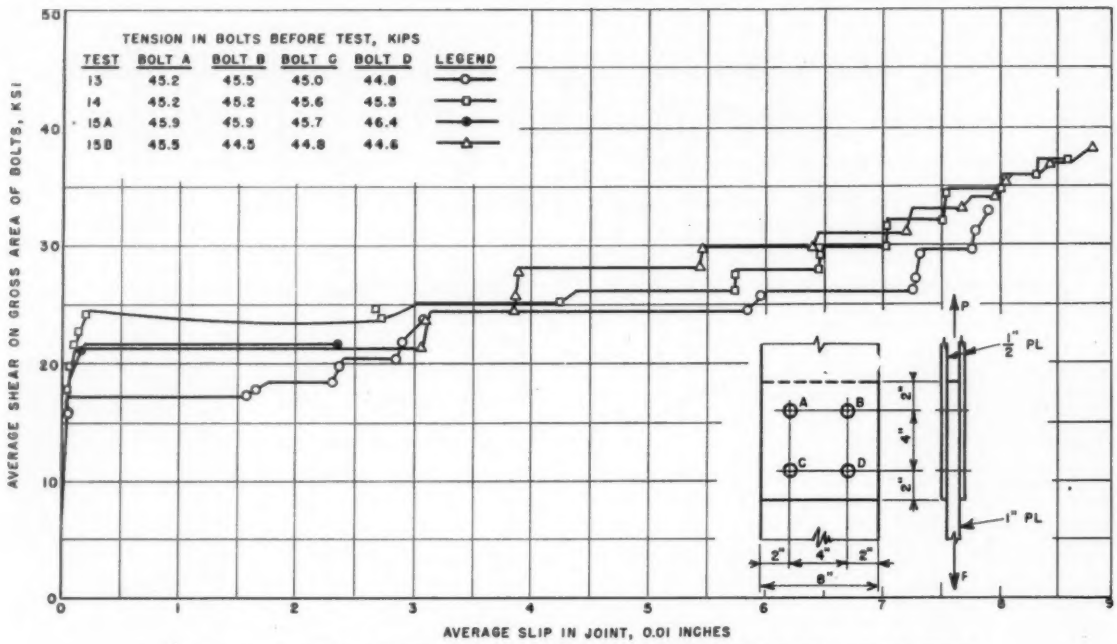

FIG. 2. COMPARISON OF NOMINAL SHEAR ON BOLTS AND AVERAGE SLIP FOR TYPICAL JOINTS

TABLE II: SUMMARY OF DATA

Spec. No. (1)	Type (2)	No. of Bolts (3)	Faying Area per Bolt sq in. (4)	Ave. Bolt Tension kips (5)	Nominal Bolt Shear		P/A at 1st slip ksi (8)	Coeffic. of Friction at 1st Slip (%) (9)
					First Slip ksi (6)	Full Bearing ksi (7)		
10	C1	4	18	45.1	19.7	25	30.8	33
11				44.8	19.4	25	30.2	33
12A				45.1	19.2	..	30.0	32
12B				45.1	21.9	27	34.3	37
								(34)
13	C	4	32	45.1	17.2	26	17.8	29
14				45.3	24.7	28	25.5	42
15A				46.0	21.6	..	22.3	36
15B				44.8	22.0	31	22.7	37
								(36)
16	C2	4	50	44.7	23.3	33	17.9	40
17				44.6	18.8	32	14.5	32
18				44.4	26.4	38	20.3	45
								(39)
19	C3	4	72	44.9	21.6	33	13.3	37
20				44.6	25.2	32	15.5	43
21				44.9	24.3	39	14.9	41
								(40)
31	C4	4	28	24.2	12.5	15	12.9	39
32				24.2	11.6	19	12.0	37
33				23.8	10.5	19	10.8	34
								(37)
37	C	4	32	35.7	15.9	24	16.4	34
38				36.5	20.2	24	20.7	42
39				35.4	16.2	24	16.7	35
								(37)
57	C4	4	28	35.8	16.9	25	17.4	36
58				37.3	18.6	27	19.2	38
59				36.8	18.1	25	18.6	37
								(37)

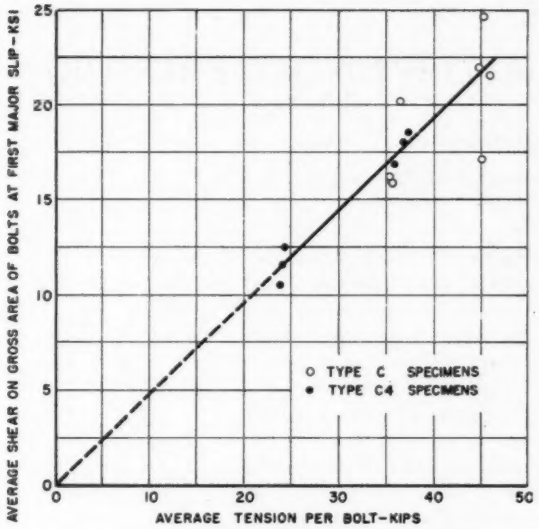
AVERAGE SHEAR ON GROSS AREA OF BOLTS AT FIRST MAJOR SLIP - KSI
AVERAGE TENSION PER BOLT - KIPS
TYPE C SPECIMENS
TYPE C4 SPECIMENS

FIG. 3. COMPARISON OF AVERAGE BOLT TENSION AND NOMINAL SHEAR ON BOLTS AT FIRST MAJOR SLIP

the end of the test was divided by the average tension before the test to obtain the quotient in per cent, which was called the residual bolt tension. A graphical comparison of the residual bolt tension and the maximum stress applied to the net section during the test is made in Fig. 4. In general, an approximately linear relationship was found between average net stresses of 27 and 48 ksi. The residual bolt tension decreased from 85 to 50 per cent as the average net stress increased from 27 to 48 ksi.

3. ***Effect of Faying Area and Net Tensile Section upon Slip of Bolted Joints.*** Types C, C1, C2, and C3 specimens were used in this series. As shown in Fig. 1, the test sections of these specimens were geometrically similar, the faying areas varying from 18 to 72 sq in. per bolt.

Because of the variation in the net cross-section area of this series of specimens, more yielding occurred in the smaller specimens than in the larger. Before the coefficients of friction could be compared, a small adjustment of their values was required to eliminate the effect of this yielding. A procedure was applied which used the experimental relationship between the residual bolt tension and the average tensile stress on the net section of the specimen shown in Fig. 4. The average tensile stress in the specimen at the load corresponding to the first major slip was computed for each specimen of this series, and is given in Table II. Figure 4 was entered with this value to obtain an approximate value of the residual bolt tension. This bolt tension was assumed to be the average bolt tension present in the joint at

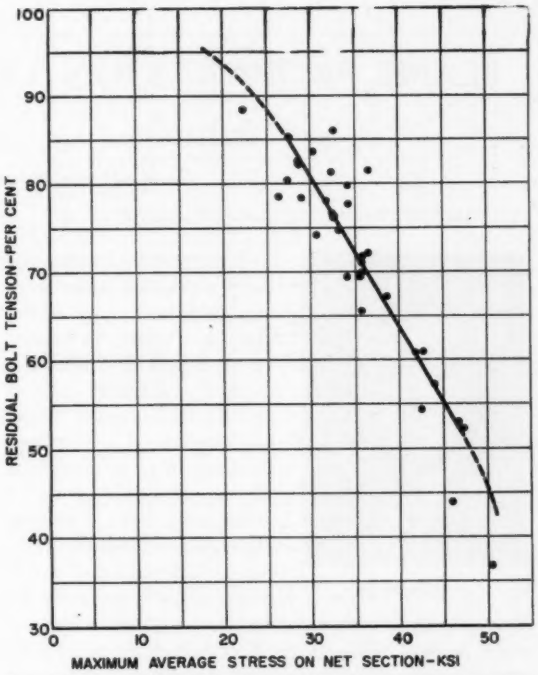

FIG. 4. RELATIONSHIP OF MAXIMUM TENSILE STRESS IN NET SECTION OF SPECIMEN TO RESIDUAL BOLT TENSION

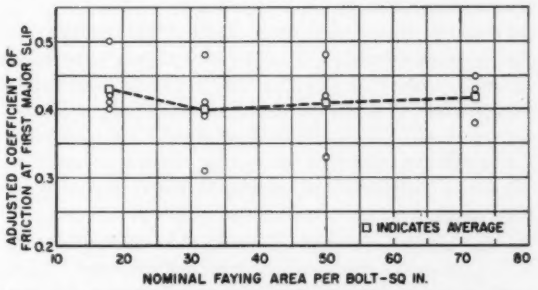

FIG. 5. COMPARISON OF ADJUSTED COEFFICIENT OF FRICTION AT FIRST MAJOR SLIP AND NOMINAL FAYING AREA

the time of the first major slip. The total clamping force was recomputed from this value of the bolt tension, and an adjusted coefficient of friction was calculated. These adjusted coefficients are compared to the nominal faying areas in Fig. 5. This plot shows almost no variation of the average coefficient of friction with respect to the faying areas of the joints.

Summary

The coefficient of friction at the first major slip did not appear to vary with the clamping force exerted by the bolts, but was approximately constant, regardless of the tension in the bolts. The coefficient of friction at the first major slip,

(Continued on page 32)

FLAME PROPAGATION VELOCITIES UNDER PRESSURE*

GLEN E. EGGLESTON

Graduate Student in Mechanical Engineering

G. E. Eggleston

The project of measuring flame velocities under varying pressures was undertaken as a means to explain, at least partially, the phenomenon of flame-front vibration that usually causes blowout in jet engines. Blowout in jet engines usually starts as an oscillation of the flame front of increasing amplitude until the flame front is carried into a region where the air-fuel ratio will not support combustion, thus causing the flame to be extinguished. This is not the only type of blowout but is the one of interest in this project.

The oscillation of the flame front may not cause blowout but frequently sets up severe vibrations in the combustion chamber that may result in physical damage to some part of the engine. This problem of flame-front vibration, though known for a great many years to exist in many types of fuel burners in boilers and furnaces, has never been satisfactorily explained or analyzed. The difficulty has usually been remedied by changing the size or shape of the combustion chamber without determining the real cause of the vibration.

The advent of the gas turbine and the jet engine to our present industries has directed increased attention to this problem. In jet aircraft engines it presents a very serious aspect and one which can cause dire consequences. An engine operating quite normally may, for no apparent reason, start a vibration of the flame front which may tear the engine from its mountings or cause blowout.

It was believed by the writer that this vibration may be partially the result of a standing sound or pressure wave in the combustion chamber which was excited by the variation in flame velocity.

Accordingly, flame velocities were measured under steady flow and quiescent burning by means of the bunsen-burner type method. They were measured for various air-fuel ratios and for various pressures up to about 50 lb per sq in. under constant temperature.

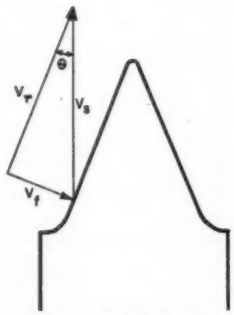

Fig. 1. Typical Flame

Figure 1 shows a sketch of a bunsen-type flame under equilibrium conditions. The flame starts at the base of the cone and is carried outward with a velocity V_s of the stream. The flame velocity V_f travels inward at an angle $90° - \theta$. The resulting path of the flame front is then along the surface of the cone at a velocity V_r until all the increments of the flame front meet at the tip of the cone. By measuring the stream velocity and the angle of the cone, it is therefore possible to calculate the flame velocity as $V_f = V_s \sin \theta$. In the actual experiments the angle was not measured but calculated from the height of the cone.

The apparatus (Fig. 2) consisted of a chamber in which a bunsen-type burner was located. With this arrangement the pressure in the chamber was varied. At each pressure the air-fuel ratio was varied to obtain the curve of flame velocity versus air-fuel ratio.

Figure 3 shows the results of flame velocity versus air-fuel ratio at various pressures for gasoline. It will be noticed that there is a decrease in flame velocity with an increase in pressure. At first this would seem to be contradictory to the theory of chemical reaction. However, on more complete examination, it was found to be entirely compatible with that theory.

Chemical reaction theory would lead us to believe

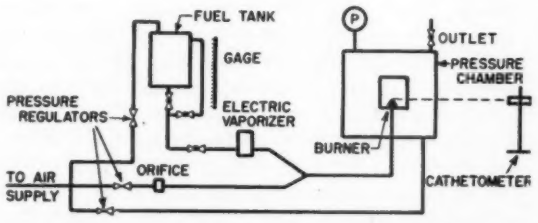

FIG. 2. BURNING CHAMBER WITH AIR AND FUEL CONTROLS

*Abstracted from the author's thesis submitted for the degree of M.S. in Mechanical Engineering, 1949. The investigation was conducted under the supervision of Michael Guidon, Instructor in Mechanical Engineering.

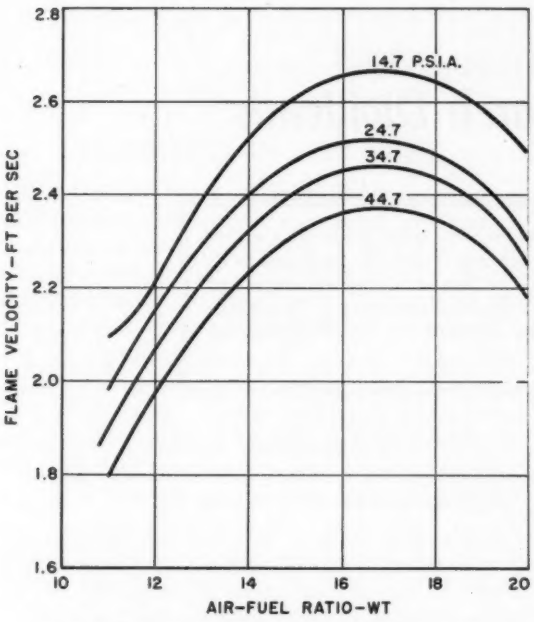

FIG. 3. FLAME VELOCITY FOR WHITE GASOLINE
Temperature: 300° F.

that as molecules come closer together at a given temperature they combine more readily. This is exactly what happened in this experiment. Although the flame velocity was less at the higher pressure, the mass rate of burning (pounds of fuel burned per unit time) was greater. By applying the information from the curves to the practical problem of the jet engine, a plausible explanation can be formulated for flame-front oscillation. It is not advanced as a final explanation because the complete solution is not so simple. It is intended only to explain the effect of pressure on the behavior of an oscillating flame front in a jet-engine combustion chamber.

Figure 4 shows a schematic cross section of a jet engine. Figure 5 shows a characteristic set of flame velocity versus air-fuel ratio curves for varying pressures. When there is no combustion, the air will pass through the engine at some constant speed represented on Fig. 5 by the line labeled V_s. As the fuel is sprayed into the combustion chamber it will form a rich mixture at the front of the chamber and will get progressively leaner as the secondary air is admitted along the chamber. If the flame starts in a region of air-fuel ratio represented by point 1, Fig. 5, the flame velocity will be greater than the stream velocity and the flame front will travel up the chamber into the richer mixture until the flame velocity is equal to the stream velocity. This is represented by line 1-2, Fig. 5. At this point the flame front will tend

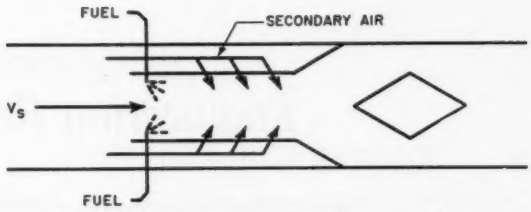

FIG. 4. SCHEMATIC CROSS SECTION OF JET ENGINE

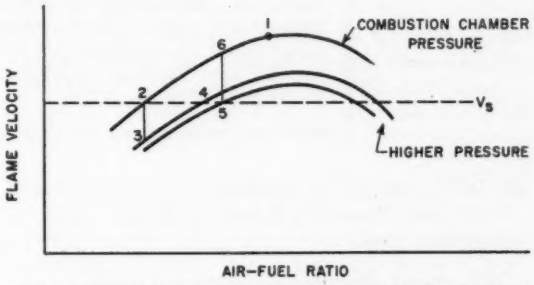

FIG. 5. EFFECT OF INCREASED PRESSURE ON FLAME VELOCITY

to remain in equilibrium unless some disturbing factor, such as nonhomogeneous mixture, temperature variation, and pressure variation, to mention only a few, should cause a change.

Consider the flame front to be in equilibrium at point 2. If the pressure were suddenly increased a small amount because of some disturbance, the flame velocity would drop to point 3. Since this velocity is below the stream velocity the flame front would be carried toward the back of the combustion chamber into a region of leaner air-fuel ratio. This is represented by the line 3-4. However, since the mass rate of burning is also temporarily increased, there will be a temporary increase in the heat release in the combustion chamber which will also tend to increase pressure with a further decrease of flame velocity. After stabilization of pressure the flame front will come to rest at some point in the combustion point 6. As the pressure wave passes the flame front and the pressure drops to its normal value the flame velocity increases to point 6 where the flame front immediately moves forward to point 2 again. If it is visualized that the oscillation of this flame front supplies enough exciting energy to maintain a standing pressure wave in the combustion chamber which in turn causes the flame velocity to change, it is not hard to conceive of the amplitude increasing to a point where the flame front is carried out of the turbine.

Although the effect of temperature and fuel distribution still presents problems, this basic theory may reveal some important facts in the solution of the burner vibration problems.

Engineering Research Dividends

Recent theses for advanced degrees, which were submitted as reports on Engineering Experiment Station research projects, will regularly appear in abstract form in *The Trend*. Complete copies of these theses are available for reference at the University of Washington Library. Address inquiries to the Director of the Engineering Experiment Station.

BRYANT, B. S., "A Study of the Impregnation of Ponderosa Pine with Synthetic Resins." M.S. in Forestry, 1948.

This report describes experimental work on impregnating small blocks on one face by applying pressure to a sponge filled with the impregnating resin. A number of commercial UF and phenol formaldehyde resins with several molecular weights and compositions were used dissolved in various solvents, and the results observed. These resins applied at a pressure of 450 psi penetrated sapwood satisfactorily, but heartwood was not permeable. By using resins of sufficiently small average molecular size, good tangential spreading near the surface of the block was obtained in both springwood and summerwood, but the degree of penetration obtained in the tests differed. Variation in moisture content from 17 to 13 per cent had no apparent effect. High solids-content phenol-formaldehyde resins impregnated better than lower solids content of the same resin, and most commercial solvents were equally suitable. The medium molecular weight range of water-soluble phenol-formadehyde resins are the most desirable impregnating resins from the standpoints of end product, cost, and ease of handling. The most desirable curing technique, from the standpoint of speed and appearance combines the use of radio-frequency curing with heated platens, with pressures below those which deform wood. To achieve the hardness of sugar maple, about 475 pounds of resin per 1,000 board feet of low molecular weight resin, to about 270 pounds of medium molecular weight would provide a retention of 15 and 8.5 grams per 2-in. by 5-in. block. With resin at 30 cents per pound, solid resin cost might vary from $143 to $80 per 1,000 board feet. This cost might be further reduced by using an alcohol-soluble phenolic resin of higher molecular weight. The report includes an extensive review of the literature on the penetration of wood by liquids.

LIN, C. S., "Electrothermic Production of Metallic Sodium From Sodium Carbonate and Carbon." M.S. in Chemical Engineering, 1949.

Studies were made of the electrothermic reduction of sodium carbonate with carbon to produce sodium metal. An arc-resistance type of continuous electric furnace, similar to those used for the reduction of phosphate rock with carbon to produce phosphorus, was found not applicable for producing sodium. A graphite-resistance type of electric furnace provided a uniform heat over the whole charge of the reaction mixture, and a convenient temperature control. Serious difficulties were caused by the condensation and separation of sodium vapor from carbon monoxide, and by the deposition of sodium carbonate and carbon which plugged the condenser. Apparently the reverse reaction occurred very rapidly when sodium vapor and carbon monoxide were cooled below the equilibrium temperature. The equilibrium temperature of the reaction $Na_2CO_3+2C \rightarrow 2Na+3CO$ was calculated to be 1080° C. The reverse reaction temperature range was experimentally found to be 1100-700° C. Various types of condensers, designed to keep a sharp temperature gradient from the outlet tube to the condenser, were used in order to separate pure sodium directly in the condenser from carbon monoxide. Either pure sodium at low yields or impure sodium at moderate conversions was obtained. Sodium-lead alloys were prepared by heating anhydrous sodium carbonate and carbon in the presence of lead with the use of resistance furnaces. Experiments were made both with stirring and without stirring. Heating at definite temperature cycles produced higher sodium content in the alloys than heating at uniform temperature. Three per cent sodium content in alloys was prepared by heating at a temperature range from 950° to 1026° C for two hours. Stirring was found to have no evident effect on the sodium content in the lead alloys.

Notes and Comments

ENGINEERS IN THE NEWS

R. A. HECHTMAN, Associate Professor of Structural Research, attended the meeting of the Research Council on Riveted and Bolted Structural Joints at Chicago, January 30-31. Research projects discussed included Project No. 76 which is sponsored on this campus under Professor Hechtman's supervision.

R. G. HENNES, Professor of Civil Engineering, presented a paper, "The Physical Interpretation of Triaxial Test Data," at the meeting of the Association of Asphalt Paving Technologists held at Denver February 5-7.

R. G. TYLER, Professor of Sanitary Engineering, read two papers before the Industrial Waste Conference at Purdue University, February 21-23, entitled "Ozonation of Cyanide Waste" and "Treatment of Chromium Waste by Ion Exchange."

A. V. EASTMAN, Professor of Electrical Engineering, and **H. M. SWARM,** instructor in the department, attended the IRE convention in New York, March 19-22, where Professor Eastman reported as a regional director and Mr. Swarm read a paper on "A New Method for the Generation of Single-Sideband Suppressed-Carrier Signals."

F. B. FARQUHARSON attended the meeting of the Committee for Cooperation with the Military of the ECRC called in the Pentagon, January 10, by the Research and Development Board, to discuss the equitable distribution of government research projects among educational institutions. As a result of the meeting a questionnaire was sent to 1,200 institutions from which data are being compiled for the Board's guidance.

G. L. PUTNAM, Research Associate in the Engineering Experiment Station, attended the meeting of the Electrochemical Society in Washington, D.C., April 8-10. Dr. Putnam, who is chairman of the Pacific Northwest Section of the Society, presented two papers. On April 12 at Cleveland he read two papers before the American Chemical Society.

D. R. YOUNG whose M.S. thesis is abstracted on pages 24-27, is on the civil engineering staff at Lehigh University where he is working toward his doctorate.

G. S. SCHALLER, Professor of Mechanical Engineering, appeared on the program of the Western Metals Congress, March 20, at San Francisco, with a paper on "Applied Welding Engineering,"

NEW RESEARCH PROJECTS

Project No. 110. Solar Heat. H. M. Hendrickson, Associate Professor of Mechanical Engineering, Supervisor; J. N. Bigford, Research Fellow.

Project 111. Utilization of Glacial Clays of Washington for Pottery Dinnerware and other Ceramic Products. P. D. Johnson, Assistant Professor of Ceramic Engineering, Supervisor. No assignment as yet.

Project No. 112. Investigation of Velocity Distribution in Square-Cornered Ducts. V. M. Ganzer, Associate Professor of Aeronautical Engineering, Supervisor; Kazuo Kumasaka, Research Fellow.

Project. No. 15. Drying Characteristics of Graphite. R. W. Moulton, Professor of Chemical Engineering, Supervisor; P. H. Cawley, Research Fellow. Sponsored by General Electric Company, Richland Project.

Project No. 116. Study of Cold Welding. B. D. Mills, Jr., Professor of Mechanical Engineering, Supervisor; Madhusudan Sengupta, Research Fellow.

Project No. 117. Microwave Spectrum Analyser. A. E. Harrison, Associate Professor of Electrical Engineering, Supervisor; A. B. Jacobsen, Instructor in Electrical Engineering. Sponsored by Office of Naval Research.

Project No. 118. Total Head Tube in Low Density Supersonic Flow. R. E. Street, Associate Professor of Aeronautical Engineering, Supervisor; J. P. Liotier, Research Fellow.

Project No. 119. Structural Behavior of Reinforced Concrete Building Frames and their Components. Part I. Beam-Column Joints. R. A. Hechtman, Associate Professor of Structural Research, Supervisor; H. C. Lee, Research Fellow.

Project No. 120. Particle Kinetics in Fluidized Beds. C. F. Gerald, Assistant Professor of Chemical Engineering, Supervisor; L. J. Gordon, Research Fellow.

Project No. 121. Heat Transfer and Mass Transfer in Spray Drying. R. W. Moulton, Professor of Chemical Engineering, Supervisor; J. A. Buckham, Research Fellow.

ELECTRODE-ELECTROLYTE TEMPERATURE DIFFERENTIALS

(Continued from page 21)

ture of the electrode surface usually controls the electrode reaction. A knowledge of ΔT may be necessary to design a cell adequately.

Moreover, failure to take into account ΔT has been a source of error in overvoltage measurements. Knobel and Joy,[6] for example, measured the temperature coefficient of overvoltage of hydrogen at current densities up to 40 amperes per square decimeter in the temperature range 0° to 70° C, and state that "the temperatures are reliable to ±0.05° C." At a current density of 40 amperes per square decimeter, Fig. 3 shows that ΔT is about 5° C from 0° to 40° C for our oxygen electrode. While the ΔT for a hydrogen electrode would probably be less because of lower overvoltage, neglecting to consider electrode heating will cause an error in the measurement of overvoltage temperature coefficients at moderate and high-current densities.

Correlation of ΔT with Viscosity. The shape of the ΔT versus electrolyte temperature curves closely resembled the viscosity data of Putnam and Clark[7] for 40 per cent perchloric acid. This suggested plotting ΔT against viscosity (Fig. 4). The viscosity is that of the main body of the electrolyte. The linear relationship indicates that viscosity is probably the controlling factor in the resistance to heat transfer. It is the usual practice in problems of natural convection to evaluate the physical properties of the system at the so-called film temperature, which is defined as the arithmetic mean temperature between the heat-transfer surface and the main body of the fluid. It is recognized that anode-film composition as well as temperature may be appreciably different from that of the bulk of the electrolyte. An attempt was made to correlate ΔT with the viscosity of 40 per cent perchloric acid at the film temperature, but the curves were not nearly as linear.

Conclusions

1. There is a considerable electrode-electrolyte temperature difference for systems of high overvoltage when operated at commercial current densities.
2. The temperature of the electrode, not the electrolyte temperature, controls the electrode process.
3. Neglecting electrode-electrolyte temperature difference will cause considerable error in the determination of the temperature coefficient of overvoltage at high-current densities.
4. For the eutectic perchloric acid system studied, the electrode-electrolyte temperature difference was a linear function of the viscosity of the bulk of the solution.

NOMENCLATURE

E = reversible cell potential, volts
F = Faraday's constant, 96,500 coulombs/equiv. or 23,070 cal./(volt) (equiv.)
ΔG = free energy of reaction, cal./gm mole
ΔH = heat of reaction, cal./gm mole
I = current, amperes
n = number of electrons taking part in reaction per molecule of reactant or product
$\Delta Q = \Delta G - \Delta H$, reversible heat liberated, cal./ mole
$\Delta Q'$ = total heat liberated at electrode, cal./gm mole
T = absolute temperature, deg Kelvin
ΔT = temperature difference between anode and electrolyte, deg C
η = overvoltage, volts
P = subscript indicating constant pressure

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7. Clark, L. H., and Putnam, G. L., *Am. Chem. Soc.*, 71, 3445-7 (1949).

SLIP OF STRUCTURAL STEEL DOUBLE-LAP JOINTS ASSEMBLED WITH HIGH-STRENGTH BOLTS PART I

(Continued from page 27)

moreover, did not appear to depend upon the nominal faying area of the joint.

The highest value of the coefficient of friction found for mill-scale plates with drilled holes was 0.45, and the lowest was 0.29. A designer could probably expect that the average coefficient of friction would be about 0.36.

ACKNOWLEDGMENTS

Funds for this cooperative investigation are being supplied by the Research Council on Riveted and Bolted Structural Joints, the Engineering Experiment Station of the University of Washington, and the Washington Toll Bridge Authority. A full account of the investigation up to the present time is contained in *The First Progress Report to the Research Council on Riveted and Bolted Structural Joints.*

NEW REPRINTS

Reprint No. 36. "Chlorination of Raw and Digested Sludge," R. G. Tyler, G. T. Orlob, F. W. Williams, *Sew. and Ind. Wastes,* July, 1950.

Reprint No. 37. "Factors Useful in Ground Grid Design for Heat Pumps," G. S. Smith, ASHVE Journal Section, *Heating, Piping, and Air Conditioning,* Jan., 1951.

Reprint No. 38. "End Restraints on Truss Members," H. E. Wessman, T. C. Kavanagh, *Transactions,* ASCE, 1950.

CORRECTION

In the list of new Engineering Experiment Station research projects published in the January issue of *The Trend* the title of Project No. 87 should read, "Olivine as a Foundry Molding Sand." Research on "The Utilization of Olivine as a Raw Material for Ceramic Bodies" is being conducted under the Edward Orton Fellowship in the School of Mineral Engineering under the supervision of Dr. P. D. Johnson, Assistant Professor of Ceramic Engineering, with James E. Dore, research fellow.

PUBLICATIONS

of the

ENGINERING EXPERIMENT STATION

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Requests for copies of publications shouldd be addressed to the Director, Engineering Experiment Station, University of Washington, Seattle 5.

BULLETINS

48. The Influence of Pipe Thickness on Re-Entrant Intake Losses. Charles William Harris. 35 pp. 1928.
55. Vacuum-Tube Control for Electric Wind-Tunnel Balances. Fred Scoville Eastman. 20 pp. 1931.
56. Constant Flow Characteristic of the Plane Orifice in Proximity to Side Walls. Charles William Harris. 18 pp. 1931.
58. Preliminary Tests of Thirteen Washington Coals in a Powdered Coal Boiler Plant at the University of Washington. George Samuel Wilson, Harry Fagan Yancey, and Joseph Daniels. 27 pp. 1931.
60. An Electromagnetic Balance for Force Measurement of Current Control. Fred Scoville Eastman, 29 pp. 1932.
61. Hydraulic Flow Characteristics of a Square-Edged Intake. Charles William Harris. 21 pp. 1932.
67. The Doherty Washer Cooler. Sybren Ruurd Tymstra. 61 pp. 1932.
72. The Derivation of the Mean Temperature Difference Between a Saturated Gas and a Cooling Liquid, and also the Derivation of the Mean Velocity of Such Gas. Sybren Ruurd Tymstra. 19 pp. 1933.
73. The Production of Sodium Nitrite from Arced Nitrogen. Edgar Allen Loew and Warren Lord Beuschlein. 54 pp. 1933.
74. The Deformation of Hard Grade Reinforcing Steel During and After Construction in a Reinforced Concrete Building. Sergius Ivan Sergev. 33 pp. 1933.
75. The Water Tube Gas Condenser. Sybren Ruurd Tymstra. 24 pp. 1934.
76. Kaolin and China Clay in the Pacific Northwest. Hewitt Wilson. 184 pp. 1934.
77. A Study of Fundamental Relations of the Mathematical Theory of Elasticity. Arthur Melvin Winslow. 25 pp. 1934.
78. Hydroelectric Power in Washington. Part III, A Brief on Proposed Grand Coulee Dams. Carl Edward Magnusson. 32 pp. 1935.
79. Cycloidal Propulsion in Air. Part I, Cycloidal Propulsion Theory; Part II, Cycloidal Propeller Development at the University of Washington. Frederick Kurt Kirsten. 87 pp. 1935.
81. Influence of Two Secondary Factors in Weir Measurement. Charles William Harris. 16 pp. 1935.
84. Equations for Calculating Three Phase Symmetrical Components. Gordon Russell Shuck. 32 pp. 1935.
85. Discharge of Three Commercial Cippoletti Weirs. Robert Bowman Van Horn. 32 pp. 1935.
86. Flexure Pivots to Replace Knife Edges and Ball Bearings. Fred Scoville Eastman. 47 pp. 1935.
87. Open Water Testing of Ship Models. Thomas McKie Rowlands. 20 pp. 1935.
88. The Properties of Quartz Sands Washed from Kaolins of the Pacific Northwest. Hewitt Wilson and Frank Joseph Zvanut. 42 pp. 1936.
90. Hydroelectric Power in Washington. Part IV, Regional Electric-Power Transmission. The Grid System. Carl Edward Magnusson. 51 pp. 1936.
91. The Analysis and Control of Landslides. Robert Graham Hennes. 57 pp. 1936.
92. Moment Equations. A Method of Analysis for Continuous Beams and Rigid Frames. Alfred Jensen. 88 pp. 1937.
93. Electric Power Markets in Washington. Part I, Electric Heating of Residences. Carl Edward Magnusson. 40 pp. 1937.
94. Evaporative and Surface Cooling. George Samuel Wilson and William Lyle Dudley. 18 pp. 1937.
95. Hydroelectric Power in Washington. Part V, A Bibliography of Technical Papers, 1926-1935. Carl Edward Magnusson. 204 pp. 1937.
96. Hydroelectric Power in Washington. Part VI, International Boundary Waters. Carl Edward Magnusson. 17 pp. 1937.
97. Strength of Concrete for Mixes of Various Proportions. Ira Leonard Collier. 28 pp. 1938.
98. Geology and Its Relation to the Occurrence of Oil in Washington. Charles Edwin Weaver. 16 pp. 1938.
99. Electric Power Markets in Washington. Part II, Residence Service Markets and a Regional Power Grid. Carl Edward Magnusson. 92 pp. 1938.
100. Modernization of a Transit System. Factors that Determine the Choice of a Vehicle. George Lisle Hoard. 36 pp. 1940.
101. Buckling Criteria and Design of Two-Story Columns. Sergius I. Sergev. 48 pp. 1940.
102. An Investigation of Prestressed Stays. T. M. Rowlands and F. C. Smith. 36 pp. 1941.
103. Bismuth Bridge Magnetic Flux Meter. George Sherman Smith. 48 pp. 1940.
104. The Telechronometer, Telephone Service Measurement in Units of Time. Lyall Baker Cochran. 68 pp. 1941.
105. Theory of Flexure of Structural Members of Non-uniform Section Alfred L. Miller. 68 pp. 1940.
106. The Shearing Strength of Cement Mortar. Frederick C. Smith and Robert Q. Brown. 32 pp. 1941.
107. A Geologic Interpretation of the Failure of the Cedar Reservoir, Washington. J. Hoover Mackin. 30 pp. 1941.
108. Silica Sands of Washington. Hewitt Wilson, Kenneth G. Skinner and Albert H. Couch. 76 pp. 1942.
109. The Number of Teeth in Contact as a Vibration Factor in Involute Cut Gears. Sybren Ruurd Tymstra. 16 pp. 1942.
110. Solutions for Torsional Vibration Frequencies by Energy Method. Arthur Melvin Winslow. 22 pp. 1943.
111. Stabilized Earth Blocks for Protective Construction. Robert G. Hennes. 24 pp. 1943.
112. Hydraulic Models. Charles W. Harris. 17 pp. 1944.
113. The Theoretical Behavior and Design of Initially Curved Struts Under an Intermediate Concentric Axial Load. Sergius I. Sergev. 32 pp. 1945.
114. The Effect of Shearing Forces on the Deflection and Strength of Beams. Sergius I. Sergev. 20 pp. 1947.
115. The Influence of Random Roughness on Flow in Pipes. Charles W. Harris. 19 pp. 1949.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part I, Investigations Prior to October, 1941. F. B. Farquharson. 103 pp. 1949.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part II, Mathematical Analyses. F. C. Smith and G. S. Vincent. 63 pp. 1950.
116. Aerodynamic Stability of Suspension Bridges with Special Reference to the Tacoma Narrows Bridge. Part III, The Investigation of Models of the Original Tacoma Narrows Bridge Under the Action of Wind. F. B. Farquharson. (In preparation.)
117. Production of Wood Coke from Waste Wood. Warren L. Beuschlein. 40 pp. 1950.

REPORTS

2. Iron and Steel Manufacture in Washington, Oregon, California, and Utah. Joseph Daniels. 69 pp. 1929.
3. Coal in Washington. Joseph Daniels. 17 pp. 1934.
4. Water Resources of Washington. Richard Gaines Tyler. 61 pp. 1938.
5. The Terminal Plan: An Improved System of Urban Transportation. Austin Vitruvius Eastman. 64 pp. 1938.
6. Chemical Utilization of the Subbituminous Coals of Washington. Lorentz A. Conradi. 83 pp. 1950.

TECHNICAL NOTES

3. The Theory of Fractional Parts Developed for Structural Beam-Column Members Preceded by an Elementary Discussion of Simple Beam and Column Design. Sybren Ruurd Tymstra. 32 pp. 1943.
4. Gaging Chart for Horizontal Cylindrical Tanks with Flat Heads or with Convex Heads. Sybren Ruurd Tymstra. 4 pp. 1944.
5. Gaging Chart for Cylindrical Tanks with Different Types of Heads. Sybren Ruurd Tymstra. 7 pp. 1945.
6. The Heat Pump for Residential Heating. G. S. Smith, H. Christensen, and A. Presson. 23 pp. 1948.